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(54) [Title of the Invention] OPTICAL COMMUNICATION DEVICE, AND METHOD OF MANUFACTURING OPTICAL COMMUNICATION DEVICE

(57) [ABSTRACT]

[Object]

To provide an optical communication device which is excellent in the light-signal transmission reliability, and makes it possible to realize reliable optical communication because the light signal transmitted in a light-signal transmitting optical path is less prone to be attenuated or absorbed by the wall surface when impinging on a wall surface of the light-signal transmitting optical path, and the loss of the light signal transmitted in the light-signal transmitting optical path is therefore less prone to occur, and, in addition, which device is reduced in size by integrating optics and electronic components required for optical communications.

[Solving Means]

An optical communication device comprising an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the IC chip implementation substrate has a light-signal transmitting optical path disposed therein which passes through the IC chip implementation substrate, and that the light-signal transmitting optical path has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[Scope of Claims]

[Claim 1]

An optical communication device comprising an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the IC chip implementation substrate has a light-signal transmitting optical path disposed therein which passes through the IC chip implementation substrate, and that the light-signal transmitting optical path has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[Claim 2]

An optical communication device comprising an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the multilayer printed wiring board includes a substrate and a conductor circuit, and has a light-signal transmitting optical path disposed therein which passes through at least the substrate, and that the light-signal transmitting optical path has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[Claim 3]

An optical communication device comprising an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the IC chip implementation substrate has a light-signal transmitting optical path

disposed therein which passes through the IC chip implementation substrate, that the multilayer printed wiring board includes a substrate and a conductor circuit, and has a light-signal transmitting optical path formed therein which passes through at least the substrate, and that each of the light-signal transmitting optical paths has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[Claim 4]

The optical communication device according to any one of claims 1 to 3, wherein the light-signal transmitting optical path includes a cavity.

[Claim 5]

The optical communication device according to any one of claims 1 to 3, wherein the light-signal transmitting optical path includes a resin composite.

[Claim 6]

The optical communication device according to any one of claims 1 to 3, wherein the light-signal transmitting optical path includes a cavity and a resin composite.

[Claim 7]

The optical communication device according to claim 5 or 6, wherein the metal layer has a roughened surface formed therein.

[Claim 8]

The optical communication device according to any one

of claims 5 to 7, wherein the resin composite constituting the light-signal transmitting optical path has a transmittance of 70% or more for the light at the communication wavelength.

[Claim 9]

A method of manufacturing an optical communication device, characterized in that an IC chip implementation substrate is produced by a process including: (a) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (b) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (c) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (d) an optical-element implementation step of implementing an optical element at such a position that a light signal can be transmitted via the penetration hole, and that, after a multilayer printed wiring board having an optical waveguide is separately produced, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[Claim 10]

A method of manufacturing an optical communication device, characterized in that, after an IC chip implementation substrate on which an optical element is implemented is produced, and, separately, a multilayer printed wiring board is produced by a process including: (A) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (B) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (C) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (D) an optical-waveguide forming step of forming an optical waveguide at such a position that a light signal can be transmitted via the penetration hole, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[Claim 11]

A method of manufacturing an optical communication device, characterized in that an IC chip implementation substrate is produced by a process including: (a) a

multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (b) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (c) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (d) an optical-element implementation step of implementing an optical element at such a position that a light signal can be transmitted via the penetration hole, and that, after a multilayer printed wiring board is separately produced by a process including: (A) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (B) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (C) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (D) an optical-waveguide forming step of forming an optical waveguide at such a position that a light signal can be transmitted via the penetration hole, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions

that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[Claim 12]

The method of manufacturing an optical communication device according to any one of claims 9 to 11, wherein, after a sealing resin composite is poured between the IC chip implementation substrate and the multilayer printed wiring board, a curing process is performed to thereby form a sealing resin layer.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Pertains]

The present invention relates to optical communication devices, and to methods of manufacturing optical communication devices.

[0002]

[Prior Art]

In recent years, attention has been focused on optical fibers mainly in the field of communication. Especially in the field of IT (Information Technology), communication technology using optical fibers is necessary to provide a high-speed Internet network. The optical fiber has features: (1) low loss, (2) broad band, (3) small diameter and light weight, (4) no induction, (5) resource saving, and others. A communication system which employs the

optical fibers having these features can considerably reduce the number of relays as compared with a communication system which employs conventional metallic cables, can be easily constructed and maintained, and can achieve economization of the communication system, and improve the reliability thereof.

[0003]

Further, with regard to the optical fiber, not only light having a single wavelength but also light having many different wavelengths can be multiplexed simultaneously via a single optical fiber. Accordingly, it is possible to realize a large capacity of a transmission path capable of dealing with a variety of applications, and to deal with video service and the like.

[0004]

For this reason, in the field of network communications such as Internet communications, it has been proposed to apply optical communication using optical fibers not only to the communications over backbone networks but also to the communications between backbone networks and terminal devices (personal computers, mobile devices, game machines or the like), and the communications between terminal devices.

[0005]

When the optical communication is used for communications between backbone networks and terminal

devices or the like, it is necessary to install an optical communication device in the terminal device. As the optical communication device, one in which a substrate is provided with optical waveguides for transmitting light signals, and optical elements, such as light receiving elements and light emitting elements, for processing light signals has been proposed.

[0006]

[Problems to be solved by the Invention]

However, conventional optical communication devices have been unsatisfactory in terms of the connection reliability. Specifically, when a package substrate on which IC chips constituting the optical communication device are implemented, optical elements such as light receiving elements and light emitting elements for processing light signals, and others are separately implemented, the device itself comes to be large, and it has therefore been difficult to reduce the size of the terminal device. In addition, if an IC chip implementation substrate having optical elements built therein, and having IC chips implemented thereon is used, although the problem that the device itself comes to be large is solved, there have been the following problems.

[0007]

Specifically, with regard to the optical-element built-in package substrate, since the optical elements are

completely embedded in the substrate, it is difficult to carry out fine tuning of alignment when the substrate is connected with external optical elements (such as optical fibers and optical waveguides). In addition, since the optical elements are embedded in the package substrate when the substrate is manufactured, the misalignment of the optical elements tends to occur. It is thought that, since a heat treatment or the like is required during the manufacturing process of the package substrate, if the optical elements are embedded in a resin layer, the misalignment of the optical elements occurs during the heat treatment. If the misalignment of the embedded optical elements occurs, the connection loss caused when the package substrate is connected to external optics (such as optical waveguides) is high, which results in the reduction in the connection reliability of the optical communication. Moreover, with regard to this optical-element built-in package substrate, when a malfunction occurs in any of the embedded optical elements, it is impossible to replace only the optical element, therefore the whole optical-element built-in package substrate is a defective product, which is disadvantageous from the economical viewpoint. Furthermore, the implementation positions of the optical elements are limited by the reservation for the light-signal transmitting optical path and the position relationship

between the optical elements and the optics (such as optical waveguides) mounted on an external substrate, which makes it difficult to make the density of the IC chip implementation substrate higher.

[0008]

In addition, with regard to such conventional terminal devices, since the IC chip implementation substrate and the optics are distant from each other, the electric wiring length is large, and signal errors and the like due to crosstalk noise and the like are prone to occur in transmitting signals.

[0009]

In order to solve such problems, the present inventors have previously invented an IC chip implementation substrate having a construction in which a conductor circuit and an interlayer resin insulation layer are formed on each side of a substrate in a stacked manner, a solder resist layer is formed as the outermost layer, an optical element is implemented thereon, and in which a light-signal transmitting optical path passing through the substrate, the interlayer resin insulation layers, and the solder resist layers is disposed. The IC chip implementation substrate can transmit input/output signals of the optical element via the light-signal transmitting optical path. In addition, if an IC chip is implemented on the IC chip implementation substrate, the distance between the IC chip

and the optical element is short, and the resulting device is excellent in the electrical-signal transmission reliability. Moreover, the IC chip implementation substrate with the IC chip implemented thereon makes it possible to integrate the electronic components and the optical elements required for optical communications, and therefore can contribute to the miniaturization of optical-communication terminal devices.

[0010]

With regard to such an IC chip implementation substrate, if an optical-path resin layer is formed in the light-signal transmitting optical path, in order to achieve excellent adhesion between the optical-path resin layer and the wall surface of the light-signal transmitting optical path, a roughened surface is formed in the wall surface by performing a roughening process such as a blackening-reducing process.

[0011]

However, since the wall surface of the light-signal transmitting optical path having such a roughened surface formed therein is black, in some cases, the optical signal transmitted in the light-signal transmitting optical path is attenuated when reflected by the wall surface, or is absorbed by the wall surface, and thus, the loss of the light signals occurs, which makes it impossible to carry out reliable optical communication due to the reduction

in the optical-signal transmission reliability. In addition, even if no roughened surface is formed in the wall surface of the light-signal transmitting optical path, since the wall surface is not glossy, in some cases, the optical signal is attenuated when reflected by the wall surface, or is absorbed by the wall surface, and thus, the loss of the light signals occurs, which makes it impossible to carry out reliable optical communication due to the reduction in the optical-signal transmission reliability.

[0012]

In addition, with regard to an optical communication device previously constructed by the present inventors, so that the optical element implemented on the IC chip implementation substrate, and an optical waveguide of a multilayer printed wiring board in which the optical waveguide is formed at a predetermined position are capable of transmitting light signals via the light-signal transmitting optical path, in some cases, the optical signal transmitted in the light-signal transmitting optical path is attenuated when reflected by the wall surface, or is absorbed by the wall surface, and thus, the loss of the light signals occurs, which makes it impossible to carry out reliable optical communication due to the reduction in the optical-signal transmission reliability.

[0013]

[Means for solving the Problem]

Under these circumstances, as a result of further detailed study, the present inventors have found that, if a glossy metal layer is formed on part of or all over the wall surface of the light-signal transmitting optical path, the light signals impinging on the wall surface of the light-signal transmitting optical path are reflected instead of being absorbed, therefore the loss of the light signals is less prone to occur, which makes it possible to carry out reliable optical communication due to the excellent optical-signal transmission reliability. As a result, the present inventors have completed an optical communication device of the present invention having the following construction.

[0014]

An optical communication device according to the first aspect of the present invention is an optical communication device comprising an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the IC chip implementation substrate has a light-signal transmitting optical path disposed therein which passes through the IC chip implementation substrate, and that the light-signal transmitting optical path has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[0015]

An optical communication device according to the second aspect of the present invention is an optical communication device comprising an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the multilayer printed wiring board includes a substrate and a conductor circuit, and has a light-signal transmitting optical path disposed therein which passes through at least the substrate, and that the light-signal transmitting optical path has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[0016]

An optical communication device according to the third aspect of the present invention is an optical communication device comprising an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the IC chip implementation substrate has a light-signal transmitting optical path disposed therein which passes through the IC chip implementation substrate, that the multilayer printed wiring board includes a substrate and a conductor circuit, and has a light-signal transmitting optical path formed therein which passes through at least the substrate, and that each of the light-signal transmitting optical paths has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[0017]

It is preferable that, in the optical communication devices of the first to third aspects of the present invention, the light-signal transmitting optical path include a cavity, include a resin composite, or include a cavity and a resin composite.

[0018]

It is preferable that, in the above optical communication devices, the metal layer have a roughened surface formed therein. In addition, it is preferable that, in the above optical communication devices, the resin composite constituting the light-signal transmitting optical path have a transmittance of 70% or more for the light at the communication wavelength.

[0019]

A method of manufacturing an optical communication device of the fourth aspect of the present invention is characterized in that an IC chip implementation substrate is produced by a process including: (a) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (b) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (c) a metal-layer forming step of forming a glossy metal

layer on a wall surface of the penetration hole; and (d) an optical-element implementation step of implementing an optical element at such a position that a light signal can be transmitted via the penetration hole, and that, after a multilayer printed wiring board having an optical waveguide is separately produced, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[0020]

A method of manufacturing an optical communication device of the fifth aspect of the present invention is characterized in that, after an IC chip implementation substrate on which an optical element is implemented is produced, and, separately, a multilayer printed wiring board is produced by a process including: (A) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (B) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (C) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (D)

an optical-waveguide forming step of forming an optical waveguide at such a position that a light signal can be transmitted via the penetration hole, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[0021]

A method of manufacturing an optical communication device of the sixth aspect of the present invention is characterized in that an IC chip implementation substrate is produced by a process including: (a) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (b) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (c) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (d) an optical-element implementation step of implementing an optical element at such a position that a light signal can be transmitted via the penetration hole, and that, after a multilayer printed wiring board is separately produced by a process including: (A) a

multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (B) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (C) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (D) an optical-waveguide forming step of forming an optical waveguide at such a position that a light signal can be transmitted via the penetration hole, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[0022]

It is preferable that, in the methods of manufacturing an optical communication device of the fourth to sixth aspects of the present invention, after a sealing resin composite is poured between the IC chip implementation substrate and the multilayer printed wiring board, a curing process be performed to thereby form a sealing resin layer.

[0023]

[Modes for carrying out the Invention]

First, description will be given of an optical

communication device of the first aspect of the present invention. The optical communication device of the first aspect of the present invention is an optical communication device including an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the IC chip implementation substrate has a light-signal transmitting optical path disposed therein which passes through the IC chip implementation substrate, and that the light-signal transmitting optical path has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[0024]

With regard to the optical communication device of the first aspect of the present invention, since the glossy metal layer formed on part of or all over the wall surface of the light-signal transmitting optical path can favorably reflect the light signal transmitted in the light-signal transmitting optical path, the light signal is less prone to be attenuated or absorbed when impinging on the wall surface of the light-signal transmitting optical path. Accordingly, with the optical communication device of the first aspect of the present invention, since the loss of the light signal transmitted in the light-signal transmitting optical path is less prone to occur, the optical communication device is excellent in the light-signal transmission reliability, making it possible

to realize reliable optical communication.

[0025]

With regard to the optical communication device of the first aspect of the present invention, in the IC chip implementation substrate constituting the optical communication device, a light-signal transmitting optical path passing through the IC chip implementation substrate is disposed. The optical communication device of the present invention, which includes the IC chip implementation substrate having such a light-signal transmitting optical path disposed therein can carry out giving and receiving of information between the optical element implemented on the IC chip implementation substrate and the optics implemented on the multilayer printed wiring board, using optical signals via the light-signal transmitting optical path.

[0026]

In the optical communication device of the first aspect of the present invention, the light-signal transmitting optical path has a glossy metal layer formed on part of or all over the wall surface thereof. If the glossy metal layer is formed on part of or all over the wall surface of the light-signal transmitting optical path in this way, when the light signal transmitted in the light-signal transmitting optical path impinges on the wall surface of the light-signal transmitting optical path, the

light signal is favorably reflected by the glossy metal layer, therefore the loss of the light signal is less prone to occur, and it is possible to improve the light-signal transmission reliability. Although the glossy metal layer is formed on part of the wall surface of the light-signal transmitting optical path, or is formed all over the wall surface thereof, if the glossy metal layer is formed on part of the wall surface of the light-signal transmitting optical path, it is preferable that the glossy metal layer be formed on the wall surface of the part of the light-signal transmitting optical path, which part passes through the substrate and the interlayer resin insulation layer. This is because, normally, the substrate and the interlayer resin insulation layer have high adhesion to metal, and a solder resist layer has low adhesion to metal.

[0027]

In addition, it is preferable that the light-signal transmitting optical path include a cavity. If the light-signal transmitting optical path includes a cavity, the formation thereof is easy, and the transmission loss is less prone to occur in transmitting the light signal via the light-signal transmitting optical path. Whether or not to make the constitution of the light-signal transmitting optical path include a cavity may be appropriately decided in consideration of the thickness of the IC chip implementation substrate or the like.

[0028]

It is also preferable that the light-signal transmitting optical path include a resin composite. If the light-signal transmitting optical path includes the resin composite, the reduction in strength of the IC chip implementation substrate can be prevented. In addition, if the light-signal transmitting optical path is comprised of the resin composite, it is possible to prevent dust, contaminants or the like from entering into the light-signal transmitting optical path, therefore it is possible to prevent the transmission of light signals from being impeded due to the existence of the dust, contaminants or the like.

[0029]

It is also preferable that the light-signal transmitting optical path include a resin composite and a cavity. If the light-signal transmitting optical path includes the resin composite and the cavity, it is possible to prevent the reduction in strength of the IC chip implementation substrate. If the light-signal transmitting optical path includes the resin composite and the cavity, it is preferable that the light-signal transmitting optical path formed in the part passing through the substrate and the interlayer resin insulation layer be comprised of the resin composite, and the light-signal transmitting optical path formed in the solder

resist layer be comprised of the cavity. This is because, normally, the substrate and the interlayer insulation layer have high adhesion to resin, and the solder resist layer has low adhesion to resin.

[0030]

Description will be given below of the optical communication device of the first aspect of the present invention with reference to the drawings. Fig. 1 is a cross-sectional view schematically showing an embodiment of the optical communication device of the first aspect of the present invention. In Fig. 1, there is shown the optical communication device with an IC chip implemented thereon.

[0031]

As shown in Fig. 1, the optical communication device 150 of the first aspect of the present invention is comprised of: the IC chip implementation substrate 120 on which the IC chip 140 is implemented; and the multilayer printed wiring board 100. The IC chip implementation substrate 120 and the multilayer printed wiring board 100 are electrically connected via solder connections 141.

[0032]

In the IC chip implementation substrate 120, conductor circuits 124 and interlayer insulation layers 122 are formed on both sides of a substrate 121 in a stacked manner. In addition, the conductor circuits between which

the substrate 121 is sandwiched, and the conductor circuits between which the interlayer insulation layer 122 is sandwiched are electrically connected using through holes 129, and via holes 127, respectively. In the IC chip implementation substrate 120, the light-signal transmitting optical paths 151 passing therethrough are formed. The light-signal transmitting optical path 151 is comprised of: an optical-path resin layer 151a formed in part of the inside of the light-signal transmitting optical path 151; and a glossy metal layer 151b which is formed on the surface of the wall surrounding the part of the optical-path resin layer 151a, which part passes through the substrate 121 and the interlayer resin insulation layer 122. Accordingly, the light-signal transmitting optical path 151 is comprised of the optical-path resin layer (the resin composite) 151a, cavities, and the surrounding metal layer 151b. Although, in the optical communication device 150 shown in Fig. 1, the light-signal transmitting optical path 151 is comprised of the optical-path resin layer (the resin composite) 151a, the cavities, and the surrounding metal layer 151b, the light-signal transmitting optical path 151 may be comprised of a cavity, and a surrounding metal layer, or may be comprised of an optical-path resin layer (the resin composite), and a surrounding metal layer.

[0033]

In addition, with regard to the IC chip implementation

substrate 120, a light receiving element 138 and a light emitting element 139 are implemented on the side thereof on which the IC chip 140 is implemented, so that the IC chip implementation substrate 120 is constructed so as to be able to transmit light signals between each of the light receiving element 138 and the light emitting element 139 and the optical waveguide 119 (119a, 119b) via the light-signal transmitting optical path 151. Moreover, as the outermost layer of the IC chip implementation substrate 120, a solder resist layer 134 provided with solder bumps is formed.

[0034]

In the multilayer printed wiring board 100, conductor circuits 104 and interlayer insulation layers 102 are formed on both sides of a substrate 101 in a stacked manner. In addition, the conductor circuits between which the substrate 101 is sandwiched, and the conductor circuits between which the interlayer insulation layer 102 is sandwiched are electrically connected using through holes 109, and via holes 107, respectively. In the outermost layer of the multilayer printed wiring board 100 on the side thereof facing the IC chip implementation substrate 120, a solder resist layer 114 provided with optical-path openings 111 and solder bumps is formed. In addition, directly under the optical-path openings 111 (111a, 111b), the optical waveguides 118 (118a, 118b) provided with

optical- changing mirrors 119 (119a, 119b) are formed.

[0035]

With regard to the optical communication device 150 having such a construction, the light signals sent from the outside via optical fibers (not shown) are introduced into the optical waveguide 118a, and then sent to the light receiving element 138 (a light receiving portion 138a) via the optical-path changing mirror 119a, the optical-path opening 111a, and the light-signal transmitting optical path 151. Thereafter, the light signals are converted into electric signals by the light receiving element 138, and then sent to the IC chip 140 via solder connections 142, the conductor circuits 124, the via holes 127, and solder connections 143.

[0036]

The electric signals sent from the IC chip 140 are sent to the light emitting element 139 via the solder connections 143, via holes 127, and solder connections 142. Thereafter, the electric signals are converted into light signals by the light emitting element 139, and then introduced from the light emitting element 139 (a light emitting portion 139a) into the optical waveguide 118b via the light-signal transmitting optical path 151, the optical-path opening 111b, and the optical- changing mirror 119b. These signals are sent out to the outside in the form of light signals via optical fibers (not shown).

[0037]

Since such an IC chip implementation substrate constituting the optical communication device of the first aspect of the present invention performs optical/electric signal conversion via the light receiving element and light emitting element implemented in the IC chip implementation substrate, that is, near the IC chip, the transmission distance of the electric signals is short, the signal transmission reliability is excellent, and it is therefore possible to deal with high speed communication. In addition, since the optics and the electronic components needed for optical communications can be integrated, the IC chip implementation substrate can contribute to the miniaturization of the optical-communication terminal equipment. Moreover, the electric signals sent from the IC chip are not only sent out to the outside via optical fibers after converted into the light signals as described above, but also sent to the multilayer printed wiring board via the solder connections, and then sent to the electronic components such as other IC chips implemented on the multilayer printed wiring board, via conductor circuits (including via holes and through holes) in the multilayer printed wiring board. With regard to the optical communication device 150 having such a construction, since the misalignment of the light receiving elements and the light emitting elements implemented on the IC chip

implementation substrate, as well as the optical waveguides formed in the multilayer printed wiring board is less prone to occur, the connection reliability concerning light signals is excellent.

[0038]

It should be noted that, although the positions where the optical waveguides are formed in the multilayer printed wiring board in Fig. 1 are on the interlayer insulation layer which is the outermost layer on the side thereof close to the IC chip implementation substrate, the positions where the optical waveguides are formed in the multilayer printed wiring board constituting the optical communication device of the first aspect of the present invention are not limited to the positions. The positions may be between interlayer insulation layers, or may be on the substrate.

[0039]

In addition, in the IC chip implementation substrate 120 shown in Fig. 1, the glossy metal layer 151b is formed on the surface of the wall surrounding the part of the light-signal transmitting optical path 151, which part passes through the substrate 121 and the interlayer resin insulation layer 122. Since the glossy metal layer is formed on the wall surfaces of the light-signal transmitting optical paths in this way, the optical communication device of the first aspect of the present

invention becomes such that, when light signals are transmitted in the light-signal transmitting optical path, the light signals are favorably reflected by the metal layer, and the loss of the light signals is therefore less prone to occur, accordingly the optical communication device is excellent in the signal transmission reliability. Although, in the IC chip implementation substrate 120 shown in Fig. 1, the metal layer 151b is formed in part of the light-signal transmitting optical path 151 (the part passing through the substrate 121 and the interlayer resin insulation layer 122), the IC chip implementation substrate constituting the optical communication device of the first aspect of the present invention may have a structure in which the metal layer is formed all over the wall surface of the light-signal transmitting optical path.

[0040]

The metal layer is a glossy metal layer, and, as the material, gold, silver, nickel, platinum, aluminum and rhodium can be named, for example. This is because all of these metals are glossy, and can favorably reflect light signals. In some cases, as the material for the metal layer, copper and palladium can be used, for example. However, these materials are prone to be oxidized, and an oxide film which reduces the glossiness of the surface of the formed metal layer is prone to be formed. For this reason, it is necessary to increase the glossiness of the surface of the

metal layer by removing the oxide film. With regard to the IC chip implementation substrate constituting the optical communication device of the first aspect of the present invention, the material for the metal layer is not limited to the above-named materials. Other metals can also be used, as long as the metal has a specular gloss or a distinctness gloss.

[0041]

The glossiness of the metal layer can be represented by using a value obtained by measuring the spectral reflectance of the metal surface. The measurement of the spectral reflectance of the metal surface can be carried out as follows: a metal film made of the material similar to that for the metal layer is formed by vacuum deposition; and the reflectance of the surface of the metal film is measured when the light with a wavelength of 0.85 μm is projected vertically to the metal film. In addition, it is preferable that the glossy metal layer in the optical communication device of the first aspect of the present invention be such that the spectral reflectance is 75% or more.

[0042]

In the optical communication device of the first aspect of the present invention, if the optical-path resin layer is formed in the light-signal transmitting optical path, it is preferable that a roughened surface be formed

in the metal layer. If the roughened surface is formed in the light-signal transmitting optical path, the adhesion between the light-signal transmitting optical path and the optical-path resin can be increased. With regard to the average roughness of the roughened surface formed in the metal layer, normally, a preferable lower limit thereof is 0.1 μm, and a preferable upper limit is 5 μm. Considering the adhesion between the conductor circuit and the interlayer insulation layer, or the like, a more preferable lower limit is 0.5 μm, and a more preferable upper limit is 3 μm. Even if no optical-path resin layer is formed in the light-signal transmitting optical path, the roughened surface may be formed in the metal layer.

[0043]

The glossy metal layer may be constituted of one layer, or may be constituted of two or more layers, that is, a plurality of layers. If the metal layer is constituted of two or more layers, it is sufficient that the metal layer (hereinafter also referred to as the innermost layer) next to the cavity or the resin composite constituting the light-signal transmitting optical path be glossy. In addition, if the metal layer is constituted of two or more layers, the roughened surface may be formed in the metal layer (the metal layer on the side near the substrate or the interlayer resin insulation layer) outside of the metal layer which is the innermost layer, and the metal layer

which is the innermost layer may be formed so as to follow the shape of the roughened surface. This is because the adhesion between the metal layers is increased, and, at the same time, the adhesion between the metal layer and the resin composite is increased. Also in this case, it is preferable that the average roughness of the roughened surface formed in the metal layer be in the range described above. In addition, it is preferable that, when the roughened surface is formed in the outer metal layer, and the metal layer which is the innermost layer is formed so as to cover the roughened surface, the metal layer which is the innermost layer be formed in such a manner that the surface thereof which abuts the resin layer covering the metal layer is as flat as possible. This is because light signals would be favorably reflected, and the loss of the light signals is less prone to occur.

[0044]

In the optical communication device of the first aspect of the present invention, when the light-signal transmitting optical path includes a resin composite, it is preferable that the resin composite have a transmittance of 70% or more for the light at the communication wavelength. If the transmittance for the light at the communication wavelength is less than 70%, the loss of the light signals is high, which can result in the deterioration of the transmission property for the light signals. It should be

noted that the transmittance for the light at the communication wavelength herein means the transmittance for the light at the communication wavelength per mm. Specifically, for example, this is a value calculated using the following equation (1) if, when the light having an intensity I_1 enters the optical-path resin layer (the resin composite), and passes through and leaves 1 mm of the optical-path resin layer, the outgoing light has an intensity I_2.

[0045]

$$\text{Transmittance (\%)} = (I_2/I_1) \times 100 \quad \ldots \quad (1)$$

[0046]

The optical-path resin layer is not particularly limited, as long as it is less absorptive in the communication wavelength range. As the material for the optical-path resin layer, thermosetting resin, thermoplastic resin, photosensitive resin, and partially-photosensitized thermosetting resin can be named, for example. Specifically, acrylic resin, such as PMMA (polymethyl methacrylate), deuterated PMMA, as well as deuterated and fluorinated PMMA; polyimide resin, such as fluorinated polyimide; epoxy resin; UV-curing epoxy resin; silicone resin, such as deuterated silicone resin; and polymers produced from benzocyclobutene can be named, for example.

[0047]

It is preferable that the optical-path resin layer contain particles, such as resin particles, inorganic particles, and metal particles. This is because, if the particles are contained, the coefficients of thermal expansion can be matched between the light-signal transmitting optical path, the substrate, the interlayer resin insulation layer, and the solder resist layer, for example, so that cracks and the like due to the difference between the coefficients of thermal expansion comes to be less prone to occur. In addition, it is possible to add fire retardancy depending on the kind of particles. As the resin particles, the particles made of thermosetting resin, thermoplastic resin, photosensitive resin, partially-photosensitized thermosetting resin, a resin composite of thermosetting resin and thermoplastic resin, or a composite of photosensitive resin and thermoplastic resin, can be named, for example.

[0048]

Specifically, the particles made of thermosetting resin, such as epoxy resin, phenol resin, polyimide resin, bismaleimide resin, polyphenylene resin, polyolefin resin, and fluoroplastic; resin produced by reacting methacrylic acid, acrylic acid or the like with the thermosetting group of these thermosetting resins (an epoxy group of the epoxy resin, for example) to introduce an acrylic group thereinto; thermoplastic resin, such as phenoxy resin,

polyether sulphone (PES), polysulphone (PSF), polyphenylene sulphone (PPS), polyphenylene sulfide (PPES), polyphenylether (PPE), and polyetherimide (PI), or the like; or photosensitive resin, such as acrylic resin, can be named, for example. The particles made of a resin composite of the above-named thermosetting resin and the above-named thermoplastic resin, or made of a resin composite which includes the above-named thermoplastic resin, and the above-named photosensitive resin or the above-named resin into which an acrylic group is introduced, can also be used. As the resin particles, resin particles made of rubber can also be used.

[0049]

As the inorganic particles, the particles made of alumina; an aluminum compound, such as aluminum hydroxide; a calcium compound, such as calcium carbonate and calcium hydroxide; a potassium compound, such as potassium carbonate; a magnesium compound, such as magnesia, dolomite, and basic magnesium carbonate; a silicon compound, such as silica and zeolite; or a titanium compound, such as titania, can be named. The particles produced by mixing silica and titania in a certain proportion, and then melting and homogenizing the mixture can also be used. As the inorganic particles, the particles made of phosphor or a phosphor compound can also be used.

[0050]

As the metal particles, the particles made of gold, silver, copper, palladium, nickel, platinum, iron, zinc, lead, aluminum, magnesium, or calcium, can be named, for example. These resin particles, inorganic particles, and metal particles may be used alone, or two or more kinds of these particles may be used in combination.

[0051]

The shape of the particles is not particularly limited. Spherical shape, oval shape, crushed-sand shape, and polyhedral shape can be named, for example. Among these shapes, the spherical shape or the oval shape is preferable. This is because, since the particles of the spherical shape or the oval shape have no edge, cracks and the like are relatively less prone to occur in the optical-path resin layer.

[0052]

It is preferable that the grain size of the particles be smaller than the communication wavelength. This is because, if the grain size is larger than the communication wavelength, the particles can impede the transmission of light signals. Two or more kinds of particles with different grain sizes may be contained, as long as the particles have grain sizes in this range. The grain size of a particle herein means the diameter across the longest part of the particle.

[0053]

A preferable lower limit of the mixing amount of the particles contained in the optical-path resin layer is 10 wt%, and a more preferable lower limit is 20 wt%. On the other hand, a preferable upper limit of the mixing amount of the particles is 80 wt%, and a more preferable upper limit is 70wt%. If the mixing amount of the particles is less than 10 wt%, the effect expected to be obtained by mixing the particles cannot be obtained in some cases. If the mixing amount of the particles is more than 80 wt%, the transmission of light signals is impeded in some cases.

[0054]

The shape of the light-signal transmitting optical path is not particularly limited. Cylindrical shape, cylindroid shape, quadrangular-prism shape, and polygonal-column shape can be named, for example. Among these shapes, the cylindrical shape is preferable. This is because it is easy to form the light-signal transmitting optical path.

[0055]

A preferable lower limit of the diameter of the cross section of the light-signal transmitting optical path is 100 μm. If the diameter of the cross section is less than 100 μm, there is a possibility that the optical path is blocked. In addition, there is a possibility that it comes to be difficult to form the optical-path resin layer in the light-signal transmitting optical path. On the other

hand, a preferable upper limit of the diameter of the cross section is 500 μm. This is because, even if the diameter is set larger than 500 μm, the transmission property for the light signals would not be significantly improved, and the paths with this diameter can be a cause of the impairment of the flexibility in designing the conductor circuits formed in the IC chip implementation substrate. A more preferable lower limit of the diameter of the cross section is 250 μm, and a more preferable upper limit is 350 μm, because the transmission property for the light signals and the design flexibility are more improved, and problems will not occur when an uncured, resin composite is filled. The diameter of the cross section of the light-signal transmitting optical path, when the light-signal transmitting optical path has a cylindrical shape, means the diameter of the cross section thereof, when the optical path has a cylindroid shape, means the major axis of the cross section thereof, and, when the optical path has a quadrangular-prism shape or a polygonal-column shape, means the length across the longest part of the cross section thereof.

[0056]

The diameter of the cross section of the part of the light-signal transmitting optical path, which part passes through the solder resist layer, may be smaller than the diameter of the cross section of the part of the light-signal

transmitting optical path, which part passes through the substrate and the interlayer resin insulation layer. Specifically, the diameter of the cross section of the part of the light-signal transmitting optical path, which part passes through the solder resist layer, may be smaller than the diameter of the cross section of the part of the light-signal transmitting optical path, which part passes through the substrate and the interlayer resin insulation layer by 20 to 150 μm. The glossy metal layer formed on the wall surface of the light-signal transmitting optical path can in some cases serve as a through hole, that is, serve to electrically connect the conductor circuits between which the substrate is sandwiched, or connect the conductor circuits between which the substrate and the interlayer resin insulation layer are sandwiched.

[0057]

In the IC chip implementation substrate constituting the optical communication device of the first aspect of the present invention, it is preferable that optical elements, such as light receiving elements and light emitting elements, be implemented. As the light receiving element, a PD (a photodiode) and an APD (an avalanche photodiode) can be named.for example. These devices may be properly used in consideration of the construction of the IC chip implementation substrate, desired characteristics, or the like. As the material for the light

receiving element, Si, Ge, and InGaAs can be named, for example. Among these materials, InGaAs is preferable in view of its excellent light-receiving sensitivity.

[0058]

As the light receiving element, an LD (a semiconductor laser), a DFB-LD (a distributed-feedback-type semiconductor laser), and an LED (a light emitting diode) can be named, for example. These devices may be properly used in consideration of the construction of the IC chip implementation substrate, desired characteristics, or the like.

[0059]

As the material for the light emitting element, a compound of gallium, arsenic, and phosphorus (GaAsP), a compound of gallium, aluminum, and arsenic (GaAlAs), a compound of gallium and arsenic (GaAs), a compound of indium, gallium, and arsenic (InGaAs), and a compound of indium, gallium, arsenic, and phosphorus (InGaAsP) can be named, for example. These materials may be properly used in consideration of the communication wavelength. For example, GaAlAs can be used if the communication wavelength is in the 0.85 μm band, while InGaAs or InGaAsP can be used if the communication wavelength is in the 1.3 μm band or in the 1.55 μm.

[0060]

In the multilayer printed wiring board constituting

the optical communication device of the first aspect of the present invention, it is preferable that the optical waveguides be formed. As the optical waveguide, an organic optical waveguide made of a polymeric material or the like, and an inorganic optical waveguide made of silica glass, a compound semiconductor, or the like, can be named, for example. Among these optical waveguides, the organic optical waveguide made of a polymeric material or the like is preferable. This is because the adhesion to the interlayer resin insulation layer is excellent, and it is easy to form the light-signal transmitting optical path.

[0061]

The polymeric material is not particularly limited, as long as it is less absorptive in the communication wavelength range. As the polymeric material, thermosetting resin, thermoplastic resin, photosensitive resin, partially-photosensitized thermosetting resin, a composite of thermosetting resin and thermoplastic resin, and a composite of photosensitive resin and thermoplastic resin can be named, for example.

[0062]

Specifically, acrylic resin, such as PMMA (polymethyl methacrylate), deuterated PMMA, as well as deuterated and fluorinated PMMA; polyimide resin, such as fluorinated polyimide; epoxy resin; UV-curing epoxy resin; polyolefin-based resin; silicone resin, such as deuterated

silicone resin; and polymers produced from benzocyclobutene can be named, for example.

[0063]

In the optical waveguides, in addition to the above resin ingredients, particles, such as resin particles, inorganic particles, and metal particles may be contained. As specific examples of the particles, the particles similar to those contained in the sealing resin layer can be named, for example.

[0064]

The shape of the particles is not particularly limited. Spherical shape, oval shape, crushed-sand shape, and polyhedral shape can be named, for example. Among these shapes, the spherical shape or the oval shape is preferable. This is because, since the particles of the spherical shape or the oval shape have no edge, cracks and the like are relatively less prone to occur in the optical waveguide.

[0065]

It is preferable that the grain size of the particles be smaller than the communication wavelength. This is because, if the grain size is larger than the communication wavelength, the particles can impede the transmission of light signals. Two or more kinds of particles with different grain sizes may be contained, as long as the particles have grain sizes in this range.

[0066]

A preferable lower limit of the mixing amount of the particles contained in the optical waveguide is 10 wt%, and a more preferable lower limit is 20 wt%. On the other hand, a preferable upper limit of the mixing amount of the particles is 80 wt%, and a more preferable upper limit is 70wt%. If the mixing amount of the particles is less than 10 wt%, the effect expected to be obtained by mixing the particles cannot be obtained in some cases. If the mixing amount of the particles is more than 80 wt%, the transmission of light signals is impeded in some cases. Although the shape of the optical waveguide is not particularly limited, a sheet shape is preferable because it is easy to form the optical waveguide.

[0067]

If the particles are contained in the optical waveguide, the coefficients of thermal expansion can be matched between the optical waveguide, and the substrate, the interlayer resin insulation layer or the like constituting the multilayer printed wiring board, accordingly, cracks, exfoliation and the like due to the difference between the coefficients of thermal expansion is less prone to occur.

[0068]

The thickness of the optical waveguide is preferably from 1 to 100 μm, and the width thereof is preferably from 1 to 100 μm. If the width is less than 1 μm, the formation

thereof is not easy in some cases. On the other hand, if the width thereof is more than 100 μm, the optical waveguide with this width can be a cause of the impairment of the flexibility in designing the conductor circuits and the like constituting the multilayer printed wiring board.

[0069]

The closer the ratio between the thickness and the width of the optical waveguide is to 1:1, the more preferable. This is because the loss caused when the light signals are transmitted increases as the ratio between the thickness and the width goes away from 1:1. In addition, if the optical waveguide is a single-mode optical waveguide for the communication wavelength of 1.55 μm, it is preferable that the thickness and the width thereof be from 5 to 15 μm. If the optical waveguide is a multi-mode optical waveguide for the communication wavelength of 0.85 μm, it is preferable that the thickness and the width thereof be from 20 to 80 μm.

[0070]

It is preferable that, as the optical waveguides, light-receiving optical waveguides and light-emitting optical waveguides be formed. The light-receiving optical waveguide means an optical waveguide for transmitting the light signals, which are sent from the outside via optical fibers and the like, to the light receiving element. The light-emitting optical waveguide means an optical

waveguide for transmitting the light signals, which are sent from the light emitting element, to optical fibers and the like. It is preferable that the light-receiving optical waveguide and the light-emitting optical waveguide be made of the same material. This is because it is easy to match the coefficients of thermal expansion and the like, and to form the optical waveguides.

[0071]

As described above, it is preferable that, in the optical waveguide, an optical-path changing mirror be formed. This is because, by forming the optical-path changing mirror, it is possible to change an optical path at a desired angle. The formation of the optical-path changing mirror can be carried out by cutting one end of the optical waveguide as described later, for example.

[0072]

Although, in the multilayer printed wiring board shown in Fig. 1, the optical waveguides are formed, and the solder resist layer is formed as the outermost layer, the solder resist layer may be formed as appropriate. For example, without forming the solder resist layer, an optical waveguide comprised of a lower cladding, a core and an upper cladding may be formed all over the interlayer resin insulation layer, and the upper cladding may serve as the solder resist layer. The optical communication device of the present invention having such a construction

can be manufactured by methods of manufacturing the optical communication device of the present invention described later.

[0073]

In the optical communication device 150 shown in Fig. 1, the IC chip implementation substrate 120 and the multilayer printed wiring board 100 are electrically connected via the solder connections 141. Accordingly, as described above, the electric signals sent from the IC chip are not only converted into light signals and then sent to the multilayer printed wiring board 100 via the light-signal transmitting optical path 151 and the like, but also sent to the multilayer printed wiring board 100 via the solder connections 141.

[0074]

When the IC chip implementation substrate and the multilayer printed wiring board are connected via the solder connections, the IC chip implementation substrate can be disposed in a predetermined position by the self-alignment effect of solder.

[0075]

The self-alignment effect is the effect that solder tends to be in a more stable shape near the centers of solder-bump forming openings due to the fluidity of the solder itself during a reflow process. It is thought that the effect is caused because the solder is repelled by the

solder resist layer, and, at the same time, large surface tension showing a tendency to make the shape spherical acts when the solder attaches to metal. Utilizing the self-alignment effect, when the IC chip implementation substrate is connected to the multilayer printed wiring board via the solder connections, the IC chip implementation substrate moves during reflow, and it is thus possible to mount the IC chip implementation substrate to the multilayer printed wiring board in a correct position, even if a misalignment between the substrate and the board has occurred before the reflow. Accordingly, in the case where light signals are transmitted between the outside optics, and the light receiving element or the light emitting element implemented on the IC chip implementation substrate via the light-signal transmitting optical path, as long as the implementation positions of the light receiving elements and the light emitting elements implemented on the IC chip implementation substrate are correct, it is possible to correctly transmit light signals between the IC chip implementation substrate and the multilayer printed wiring board.

[0076]

In the optical communication device, a microlens may be disposed at at least one end of the light-signal transmitting optical path. The microlens may be directly disposed at the end of the light-signal transmitting

optical path, may be disposed with an adhesive layer interposed therebetween, or, in some cases, may be disposed in the optical-path resin layer in the light-signal transmitting optical path, for example.

[0077]

In addition, it is preferable that the refractive index of the microlens disposed at one end (on the multilayer printed wiring board side) of the light-signal transmitting optical path be larger than the refractive index of the optical-path resin layer formed in the light-signal transmitting optical path. If the microlens with such a refractive index is disposed, it is possible to condense the light signals in a desired direction, accordingly it is possible to transmit the light signals more surely.

[0078]

If the microlens is a convex lens, the radius of curvature of the convex surface of this lens may be selected as appropriate in consideration of the design of the light-signal transmitting optical path and the like. Specifically, if the focal length has to be long, it is preferable that the radius of curvature be small. If the focal length has to be short, it is preferable that the radius of curvature be large.

[0079]

The microlens is not particularly limited, and one which is used as an optical lens can be named. As specific

examples of the material for the lens, optical glass and optical-lens resin can be named, for example. As the optical-lens resin, acrylic resin, such as PMMA (polymethyl methacrylate), deuterated PMMA, as well as deuterated and fluorinated PMMA; polyimide resin, such as fluorinated polyimide; epoxy resin; UV-curing epoxy resin; polyolefin-based resin; silicone resin, such as deuterated silicone resin; and polymers produced from benzocyclobutene can be named, for example.

[0080]

If the microlens(s) is disposed at the end(s) of the light-signal transmitting optical path, the microlens(s) may be directly disposed at the end(s) of the light-signal transmitting optical path. Especially, if the optical-path resin layer is formed in the light-signal transmitting optical path (the part thereof passing through the solder resist layer), it is preferable that the microlens(s) be directly disposed in the optical-path resin layer.

[0081]

Although the position at which the microlens is disposed is preferably the opposite end of the light-signal transmitting optical path to the light receiving element or the light emitting element, the position is not limited to this position. The microlens may be disposed at the end of the light-signal transmitting optical path on the light

receiving (emitting) element side, or may be disposed at each end of the light-signal transmitting optical path, for example. With regard to the shape of the microlens, in addition to the convex lens, any lens can be used, as long as the lens can condense the light signals in a desired direction.

[0082]

Embodiments of the optical communication device of the first aspect of the present invention are not limited to the embodiment shown in Fig. 1. An embodiment as shown in Fig. 2 can be adopted, for example. In Fig. 2, there is shown an optical communication device with an IC chip implemented thereon. As shown in Fig. 2, the optical communication device 250 is comprised of: the IC chip implementation substrate 220 on which the IC chip 240 is implemented; and the multilayer printed wiring board 200. The IC chip implementation substrate 220 and the multilayer printed wiring board 200 are electrically connected via solder connections 241. In addition, a sealing resin layer 260 is formed between the IC chip implementation substrate 220 and the multilayer printed wiring board 200.

[0083]

In the IC chip implementation substrate 220, conductor circuits 224 and interlayer insulation layers 222 are formed on both sides of a substrate 221 in a stacked manner. In addition, the conductor circuits between which

the substrate 221 is sandwiched, and the conductor circuits between which the interlayer insulation layer 222 is sandwiched are electrically connected using through holes 229, and via holes 227, respectively. In the IC chip implementation substrate 220, the light-signal transmitting optical paths 251 passing therethrough are formed. The light-signal transmitting optical path 251 is comprised of: an optical-path resin layer 251a formed in part of the inside of the light-signal transmitting optical path 251; and a glossy metal layer 251b which is formed on the surface of the wall surrounding the part of the optical-path resin layer 251a, which part passes through the substrate 221 and the interlayer resin insulation layer 222. Accordingly, the light-signal transmitting optical path 251 is comprised of the optical-path resin layer 251a, cavities, and the surrounding metal layer 251b.

[0084]

In the multilayer printed wiring board 200, conductor circuits 204 and interlayer insulation layers 202 are formed on both sides of a substrate 201 in a stacked manner. In addition, the conductor circuits between which the substrate 201 is sandwiched, and the conductor circuits between which the interlayer insulation layer 202 is sandwiched are electrically connected using through holes 209, and via holes 207, respectively. In the outermost layer of the multilayer printed wiring board 200 on the

side thereof facing the IC chip implementation substrate 220, a solder resist layer 214 provided with optical-path openings 211 and solder bumps is formed. In addition, directly under the optical-path openings 211 (211a, 211b), optical waveguides 218 (218a, 218b) provided with optical-changing mirrors 219 (219a, 219b) are formed. In the optical-path opening 211, an optical-path resin layer 208 (208a, 208b) is formed.

[0085]

With regard to the optical communication device 250 having such a construction, the light signals sent from the outside via optical fibers (not shown) are introduced into the optical waveguide 218a, and then sent to a light receiving element 238 (a light receiving portion 238a) via the optical-path changing mirror 219a, the optical-path opening 211a, the sealing resin layer 260, and the light-signal transmitting optical path 251. Thereafter, the light signals are converted into electric signals by the light receiving element 238, and then sent to the IC chip 240 via the conductor circuits and solder connections.

[0086]

The electric signals sent from the IC chip 240 are sent to a light emitting element 239 via the solder connections, and conductor circuits. Thereafter, the electric signals are converted into light signals by the light emitting element 239, and then the light signals are

introduced from the light emitting element 239 (a light emitting portion 239a) into the optical waveguide 218b via the light-signal transmitting optical path 251, the sealing resin layer 260, the optical-path opening 211b, and the optical- changing mirror 219b. These signals are sent out to the outside in the form of light signals via optical fibers (not shown).

[0087]

In the optical communication device 250 shown in Fig. 2, the sealing resin layer 260 is formed between the IC chip implementation substrate 220 and the multilayer printed wiring board 200. The optical communication device in which the sealing resin layer is formed between the IC chip implementation substrate and the multilayer printed wiring board is such that dust, contaminants or the like being suspended in the air will not enter into the gap between the optical element and the optical waveguide, and the transmission of the light signals is not impeded by the existence of the dust or the contaminants, accordingly the device is more excellent in reliability.

[0088]

The sealing resin layer is not particularly limited, as long as it is less absorptive in the communication wavelength range. As the material for the sealing resin layer, the materials similar to those for the optical-path resin layer formed in the light-signal transmitting optical

path in the optical communication device of the first aspect of the present invention, can be named, for example.

[0089]

It is preferable that the sealing resin layer have a transmittance of 70% or more for the light at the communication wavelength. If the transmittance for the light at the communication wavelength is less than 70%, the loss of the light signals is high, which can result in the reduction in the reliability of the optical communication device. The meaning of the transmittance for the light at the communication wavelength is as described above.

[0090]

It is preferable that the sealing resin layer contain particles, such as resin particles, inorganic particles, and metal particles. This is because, if the particles are contained, the coefficient of thermal expansion of the sealing resin layer can be matched with those of the IC chip implementation substrate and the multilayer printed wiring board, accordingly, cracks and the like due to the difference between the coefficients of thermal expansion is less prone to occur. As specific examples of the particles, the particles similar to those contained in the optical-path resin layer described in relation to the IC chip implementation substrate constituting the optical communication device of the first aspect of the present

invention, can be named, for example.

[0091]

With regard to the optical communication device of the first aspect of the present invention, it is preferable that the refractive index of the light-signal transmitting optical path be smaller than the refractive index of the sealing resin layer. In this case, the light signals, which are transmitted via the light-signal transmitting optical path, are condensed toward the light receiving portion of the light receiving element, so that it is possible to transmit the light signals more surely. The light signals sent from the light emitting element are refracted at the interface between the light-signal transmitting optical path and the sealing resin layer in directions such that the light does not spread, accordingly, the light signals are more surely transmitted toward the optical waveguide via the sealing resin layer.

[0092]

With regard to the optical communication device, it is preferable that the light-signal transmitting optical path have the metal layer formed on the wall surface thereof, and have the optical-path resin layer formed throughout the inside thereof as shown in Fig. 2. When the sealing resin layer is formed, if the inside of the light-signal transmitting optical path is constituted of the cavity, the sealing resin layer may enter into part of the

light-signal transmitting optical path, which can impede the transmission of light signals.

[0093]

In addition, with regard to the optical communication device, it is preferable that the optical-path resin layer be formed also in the optical-path openings provided to the multilayer printed wiring board. In this case, it is preferable that the refractive index of the resin composite be smaller than the refractive index of the sealing resin layer. In this case, the light signals, which are transmitted from the IC chip implementation substrate, are condensed toward the optical-path changing mirror of the optical waveguide formed in the multilayer printed wiring board, so that it is possible to transmit the light signals more surely. The light signals sent from the optical waveguide are refracted at the interface between the optical-path opening and the sealing resin layer in directions such that the light does not spread, therefore the light signals are more surely transmitted toward the light-signal transmitting optical path via the sealing resin layer.

[0094]

If the optical-path resin layer is formed in the light-signal transmitting optical path and is also formed in the optical-path opening, moreover the thickness of the light-signal transmitting optical path and the thickness

of the optical-path opening are substantially the same, it is preferable that the refractive indices of both optical-path resin layers be smaller than the refractive index of the sealing resin layer, and be substantially the same. This is because it is possible to transmit light signals between the optical element and the optical waveguide more surely. The optical communication device of the first aspect of the present invention having such a construction can be manufactured by a method of manufacturing an optical communication device of the fourth aspect of the present invention to be described later, for example.

[0095]

Description will now be given of the method of manufacturing an optical communication device of the fourth aspect of the present invention. The method of manufacturing an optical communication device of the fourth aspect of the present invention is characterized in that an IC chip implementation substrate is produced by a process including: (a) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (b) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (c) a metal-layer forming step of

forming a glossy metal layer on a wall surface of the penetration hole; and (d) an optical-element implementation step of implementing an optical element at such a position that a light signal can be transmitted via the penetration hole, and that, after a multilayer printed wiring board having an optical waveguide is separately produced, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[0096]

With regard to the IC chip implementation substrate constituting the optical communication device manufactured by the method of manufacturing an optical communication device of the fourth aspect of the present invention, the optical element is implemented at a predetermined position, the glossy metal layer is formed on part of or all over the wall surface of the light-signal transmitting optical path, and the metal layer can favorably reflect the light signal transmitted in the light-signal transmitting optical path. Accordingly, since the light signal is less prone to be attenuated or absorbed when impinging on the wall surface of the light-signal transmitting optical path, and the loss of

the light signal transmitted in the light-signal transmitting optical path is therefore less prone to occur, the optical communication device is excellent in the light-signal transmission reliability, making it possible to realize reliable optical communication. Accordingly, with the method of manufacturing an optical communication device of the fourth aspect of the present invention, it is possible to manufacture an optical communication device in which the connection loss between the implemented optical components is low, and which is excellent in the connection reliability.

[0097]

The manufacture of the optical communication device can be carried out by, for example, producing the IC chip implementation substrate and the multilayer printed wiring board separately, and then connecting both of them via solder or the like. Accordingly, in relation to this embodiment, description will first be given of respective processes of producing the IC chip implementation substrate and the multilayer printed wiring board separately, and description will then be given of a method of connecting both of them.

[0098]

Description will be given below of the process of producing the IC chip implementation substrate. Description will first be given of the step (a), the

multilayer-interconnection-board producing step of producing the multilayer interconnection board in order of steps. Specifically, the multilayer interconnection board can be produced through the steps (1) to (9) below, for example.

(1) An insulating substrate is used as the starting material, and the conductor circuits are first formed on the insulating substrate. As the insulating substrate, a glass-epoxy substrate, a polyester substrate, a polyimide substrate, a bismaleimide-triazine resin (BT resin) substrate, a thermosetting polyphenylene ether substrate, a copper-clad laminate, and an RCC substrate can be named, for example. A ceramic substrate, such as an aluminum nitride substrate, or a silicon substrate may also be used. The conductor circuits can be formed by forming a solid conductor layer on a surface of the insulating substrate by an electroless plating process or the like, and then performing an etching process. Instead, the conductor circuits may be formed by performing an etching process to the copper-clad laminate or the RCC substrate.

[0099]

If the conductor circuits between which the insulating substrate is sandwiched are connected using through holes, the through holes are beforehand formed by forming penetration holes in the insulating substrate by the use of a drill, a laser or the like, and then performing

electroless plating or the like. The diameter of the penetration holes for the through holes is typically from 100 to 300 μm. If the through holes are formed, it is preferable that a resin filler be filled into the through holes.

[0100]

(2) Subsequently, a roughened-surface forming process is performed to the surfaces of the conductor circuits appropriately. As the roughened-surface forming process, a blackening (oxidizing)-reducing process, an etching process using, for example, an etchant containing cupric complex and organic salt, and a Cu-Ni-P needle-like alloy plating process can be named, for example. If the roughened surface is formed in this step, normally, a lower limit of the average roughness of the roughened surface is preferably 0.1 μm, and an upper limit thereof is preferably 5 μm. In consideration of the adhesion between the conductor circuit and the interlayer resin insulation layer, and of the influence on the electric-signal transmission performance of the conductor circuits, it is more preferable that a lower limit of the average roughness be 2 μm, and that an upper limit thereof be 4 μm. It should be noted that this roughened-surface forming process may be performed before the resin filler is filled into the through holes so that the roughened surfaces is also formed in the wall surfaces of the through holes. This is because

the adhesion between the through holes and the resin filler is improved.

[0101]

(3) Subsequently, on the substrate on which the conductor circuits have been formed, formed is an uncured, resin layer made of thermosetting resin, photosensitive resin, a resin prepared by introducing a photosensitive group into part of thermosetting resin, or a resin composite containing these resins and thermoplastic resin, or is a resin layer made of thermoplastic resin. For forming these resin layers, a resin similar to that used for the substrate may also be used, for example. The uncured, resin layer can be formed by applying an uncured resin via a roll coater, a curtain coater or the like, or by heat and pressure lamination of an uncured (semi-cured), resin film. The resin layer made of thermoplastic resin can be formed by heat and pressure lamination of a resin, formed material which has been formed into a film.

[0102]

Among these methods, the method in which heat and pressure lamination of an uncured (semi-cured), resin film is performed is preferable. The pressure lamination of the resin film can be performed using a vacuum laminator or the like, for example. The pressure lamination conditions are not particularly limited, and may be selected as appropriate in consideration of the composition of the

resin film, or the like. Normally, it is preferable that the pressure lamination be performed under the conditions: a pressure of 0.25 to 1.0 MPa, a temperature of 40°C to 70°C, a degree of vacuum of 13 to 1300 Pa, and a time period of approximately 10 to 120 s.

[0103]

As the thermosetting resin, epoxy resin, phenol resin, polyimide resin, polyester resin, bismaleimide resin, polyolefin-based resin, polyphenylene ether resin, polyphenylene resin, and fluoroplastic resin can be named, for example. As specific examples of the epoxy resin, novolac type epoxy resin, such as phenol-novolac type epoxy resin and cresol-novolac type epoxy resin; and dicyclopentadiene-modified alicyclic epoxy resin can be named, for example.

[0104]

As the photosensitive resin, acrylic resin can be named, for example. As the resin prepared by introducing a photosensitive group into part of thermosetting resin, one prepared by causing an acrylating reaction between the thermosetting group of the thermosetting resin, and a methacrylic acid or an acrylic acid can be named, for example.

[0105]

As the thermoplastic resin, phenoxy resin, polyether sulphone (PES), polysulphone (PSF), polyphenylene

sulphone (PPS), polyphenylene sulfide (PPES), polyphenylene ether (PPE), and polyetherimide (PI) can be named, for example.

[0106]

The resin composite is not particularly limited, as long as the resin composite contains thermoplastic resin, and thermosetting resin or photosensitive resin (including a resin prepared by introducing a photosensitive group into part of thermosetting resin). As specific combinations of thermosetting resin and thermoplastic resin, phenol resin/polyether sulphone, polyimide resin/polysulphone, epoxy resin/polyether sulphone, and epoxy resin/phenoxy resin can be named, for example. As specific combinations of photosensitive resin and thermoplastic resin, acrylic resin/phenoxy resin, and epoxy resin prepared by acrylating part of the epoxy group/polyether sulphone can be named, for example.

[0107]

With regard to the mixing ratio of thermoplastic resin, and thermosetting resin or photosensitive resin in the resin composite, preferable is thermosetting resin or photosensitive resin/thermoplastic resin = 95/5 to 50/50. This is because it is possible to ensure high toughness without deteriorating heat resistance.

[0108]

In addition, the resin layer may be comprised of two

or more different resin layers. Specifically, for example, a lower layer is formed of a resin composite with a mixing ratio of thermosetting resin or photosensitive resin/thermoplastic resin = 50/50, and an upper layer is formed of a resin composite with a mixing ratio of thermosetting resin or photosensitive resin/thermoplastic resin = 90/10. With this construction, it is possible to ensure excellent adhesion between the resin layer and the insulating substrate, and to ensure ease of formation of via-hole openings and the like in later steps.

[0109]

Moreover, the resin layer may be formed using a resin composite for roughened surface formation. The resin composite for roughened surface formation is, for example, one in which a substance soluble in a roughening solution containing at least one kind selected from an acid, an alkali and an oxidizing agent is dispersed in an uncured heat resistant resin matrix which is hardly soluble in a roughening solution containing at least one kind selected from an acid, an alkali and an oxidizing agent. With regard to the terms "hardly soluble" and "soluble", when substances are immersed in the same roughening solution for the same period of time, the substances which have a relatively high dissolution speed are called "soluble" substances, and those which have a relatively slow dissolution speed are called "hardly soluble" substances,

for the sake of convenience.

[0110]

The heat resistant resin matrix is preferably capable of keeping the shape of a roughened surface at the time of forming the roughened surface in an interlayer resin insulation layer with the use of the above-mentioned roughening solution. For example, thermosetting resin, thermoplastic resin, and a composite of these resins can be named. Photosensitive resin may also be used. If photosensitive resin is used, via-hole openings can be formed in the interlayer resin insulation layer by an exposure and development process.

[0111]

As the thermosetting resin, epoxy resin, phenol resin, polyimide resin, polyolefin resin, and fluoroplastic can be named, for example. In addition, when the thermosetting resin is photosensitized, the thermosetting group is (meth)acrylated using a methacrylic acid, an acrylic acid or the like.

[0112]

As the epoxy resin, cresol-novolac type epoxy resin, bisphenol A type epoxy resin, bisphenol F type epoxy resin, phenol-novolac type epoxy resin, alkyl phenol-novolac type epoxy resin, biphenol F type epoxy resin, naphthalene type epoxy resin, dicyclopentadiene type epoxy resin, epoxidized compounds of condensates of phenol and aromatic

aldehyde with a phenolic hydroxyl group, triglycidyl isocyanurate, alicyclic epoxy resin can be named, for example. These resins may be used alone, or two or more kinds of these resins may be used in combination. With the resins, the resin layer comes to be excellent in heat resistance and the like.

[0113]

As the thermoplastic resin, phenoxy resin, polyether sulphone, polysulphone, polyphenylene sulphone, polyphenylene sulfide, polyphenyl ether, and polyetherimide can be named, for example. These resins may be used alone, or two or more kinds of these resins may be used in combination.

[0114]

It is preferable that the substances soluble in a roughening solution containing at least one kind selected from an acid, an alkali and an oxidizing agent be at least one kind selected from inorganic particles, resin particles, and metal particles.

[0115]

As the inorganic particles, particles made of an aluminum compound, such as alumina and aluminum hydroxide; a calcium compound, such as calcium carbonate and calcium hydroxide; a potassium compound, such as potassium carbonate; a magnesium compound, such as magnesia, dolomite, basic magnesium carbonate and talc; and a silicon compound,

such as silica and zeolite, can be named, for example. These particles may be used alone, or two or more kinds of these particles may be used in combination.

[0116]

As the resin particles, particles made of thermosetting resin, thermoplastic resin or the like, can be named, for example. The resin particles are not particularly limited, as long as the particles have a dissolution speed higher than that of the heat resistant resin matrix when these are immersed in a roughening solution containing at least one kind selected from an acid, an alkali and an oxidizing agent. Specifically, amino resin (melamine resin, urea resin, guanamine resin or the like), epoxy resin, phenol resin, phenoxy resin, polyimide resin, polyphenylene resin, polyolefin resin, fluororesin and bismaleimide-triazine resin can be named, for example. These resin particles may be used alone, or two or more kinds of these resin particles may be used in combination. It is necessary that the resin particles are beforehand subjected to a curing process. If the resin particles have not been cured, the resin particles would be dissolved in a solvent for dissolving the resin matrix. As the resin particles, rubber particles, liquid-phase resin, liquid-phase rubber or the like may also be used.

[0117]

As the metal particles, gold, silver, copper, tin,

zinc, stainless steel, aluminum, nickel, iron, and lead can be named, for example. These metal particles may be used alone, or two or more kinds of these particles may be used in combination. In order to ensure the insulating property, the surfaces of the metal particles may be coated with resin on the surface thereof.

[0118]

When two or more kinds of the soluble substances are mixed to use, with regard to the combination of the two soluble substances to be mixed, a combination of resin particles and inorganic particles is preferable. The reason is as follows. Since both the resin particles and the inorganic particles are low in electrical conductivity, it is possible to ensure the insulating property of the interlayer resin insulation layer. In addition, it is easy to adjust thermal expansion in relation to the hardly soluble resin, accordingly the occurrence of cracks in the interlayer resin insulation layer made of the resin composite for roughening surface formation can be prevented, and the occurrence of exfoliation between the interlayer resin insulation layer and the conductor circuits can be prevented.

[0119]

As the acid used as the roughening solution, phosphoric acid, hydrochloric acid, sulfuric acid, nitric acid, organic acid, such as formic acid and acetic acid

can be named, for example. Among these acids, it is preferable to use organic acid. This is because organic acid is less corrosive to the conductor circuits exposed from the bottoms of the via holes when a roughening process is performed. It is preferable that, as the oxidizing agent, an aqueous solution containing chromic acid, a chromic acid mixture, an alkaline permanganate (e.g., potassium permanganate) or the like be used. As the alkali, an aqueous solution containing sodium hydroxide, potassium hydroxide or the like is preferable.

[0120]

The average grain size of the soluble substance is preferably 10 μm or less. Coarse particles with a relatively large average grain size of 2 μm or less and fine particles with a relatively small average grain size may also be used in combination. Specifically, a soluble substance with an average grain size of 0.1 to 0.5 μm and a soluble substance with an average grain size of 1 to 2 μm may be used in combination, for example.

[0121]

If average particles, the relatively large, coarse particles, and the fine particles with a relatively small average grain size are used in combination, it is possible to eliminate the solution residue of the electroless-plating film, to reduce the amount of palladium catalyst under the plating resist, and to form a shallow,

complicated roughened surface. In addition, if the complicated roughened surface is formed, it is possible to maintain a practical peel strength even when the roughened surface has small irregularities. It is preferable that the average grain size of the coarse particles be larger than 0.8 μm and smaller than 2.0 μm, and that of the fine particles be from 0.1 to 0.8 μm.

[0122]

(4) Subsequently, if an interlayer resin insulation layer using thermosetting resin or a resin composite as the material therefor is formed, an uncured, resin layer is subjected to a curing treatment, and via-hole openings are formed in the resin layer to thereby obtain the interlayer resin insulation layer. In this step, penetration holes may be formed as appropriate. It is preferable that the via-hole openings be formed by a laser process. If photosensitive resin is used as the material for the interlayer resin insulation layer, the via-hole openings may be formed by an exposure and development process.

[0123]

In addition, if an interlayer insulating layer using the thermoplastic resin as the material is formed, the via-hole openings are formed in the resin layer made of thermoplastic resin to thereby obtain the interlayer resin insulation layer. In this case, the via-hole openings can

be formed by performing a laser process. If the penetration holes are formed in this step, the penetration holes may be formed by drilling, a laser process or the like.

[0124]

As the laser used in the laser process, a CO_2 laser, a UV laser, and an excimer laser can be named, for example. Among these lasers, the excimer laser or a short-pulse CO_2 laser is preferable.

[0125]

Among excimer lasers, a hologram type excimer laser is preferably used. A hologram type excimer laser is a laser which applies a laser beam onto a target through a hologram, a condensing lens, a laser mask, a transfer lens and others. If this scheme is used, it is possible to efficiently form a large number of openings in the resin film layer by one-time irradiation.

[0126]

If the CO_2 laser is used, the pulse intervals are preferably from 10^{-4} to 10^{-8} seconds. In addition, it is preferable that a period of time for applying a laser beam to form openings be from 10 to 500 μs. By applying a laser beam through optical-system lenses and a mask, it is possible to form a large number of via-hole openings at one time. This is because, if the optical-system lenses and the mask are interposed, a laser beam with the same intensity and the same irradiation intensity can be applied

to a plurality of portions. After the via-hole openings are formed in this way, a desmear process may be performed as appropriate.

[0127]

(5) Subsequently, the conductor circuits are formed on the surface of the interlayer resin insulation layer including inner walls of the via-hole openings. In forming the conductor circuits, a thin film conductor layer is first formed on the surface of the interlayer resin insulation layer. The thin film conductor layer can be formed by electroless plating, sputtering or the like.

[0128]

As the materials for the thin film conductor layer, copper, nickel, tin, zinc, cobalt, thallium and lead can be named, for example. Among these materials, the thin film conductor layer made of copper, or copper and nickel is preferable because of its excellent electric characteristics, economical advantage and the like. With regard to the thickness of the thin film conductor layer, if the thin film conductor layer is formed by electroless plating, a preferable lower limit is 0.3 μm, and a more preferable lower limit is 0.6 μm. On the other hand, a preferable upper limit is 2.0 μm, and a more preferable upper limit is 1.2 μm. If the thin film conductor layer is formed by sputtering, the thickness is preferably from 0.1 to 1.0 μm.

[0129]

The roughened surface may be formed in the surface of the interlayer resin insulation layer before the thin film conductor layer is formed. If the roughened surface is formed, it is possible to improve the adhesion between the interlayer resin insulation layer and the thin film conductor layer. Especially, if the interlayer resin insulation layer is formed using the resin composite for roughened surface formation, it is preferable to form the roughened surface with the use of an acid, an oxidizing agent or the like.

[0130]

If the penetration holes are formed in the step (4), the thin film conductor layer may be formed also on the wall surfaces of the penetration holes at the time of forming the thin film conductor layer on the interlayer resin insulation layer, to thereby obtain through holes.

[0131]

(6) Subsequently, a plating resist is formed on the interlayer resin insulation layer on the surface of which the thin film conductor layer has been formed. The plating resist can be formed by laminating a photosensitive dry film, closely arranging a photomask made of a glass substrate or the like on which a plating resist pattern is drawn, and performing an exposure and development process, for example.

[0132]

(7) Thereafter, electroplating is performed using the thin film conductor layer as a plating bar to thereby form an electroplating layer on the plating-resist non-formed part. The electroplating is preferably copper plating. The thickness of the electroplating layer is preferably from 5 to 20 μm.

[0133]

Thereafter, by removing the plating resist and the thin film conductor layer under the plating resist, the conductor circuits (including via holes) can be formed. The removal of the plating resist may be performed using an alkaline aqueous solution or the like, for example, and the removal of the thin film conductor layer may be performed using an etchant containing a solution mixture of sulfuric acid and hydrogen peroxide, sodium persulfate, ammonium persulfate, ferric chloride, cupric chloride or the like. After the conductor circuits are formed, the catalyst on the interlayer resin insulation layer may be removed using an acid or an oxidizing agent as appropriate. This is because it is possible to prevent the deterioration of electric characteristics. Alternatively, instead of the method in which, after the plating resist is formed, the electroplating layer is formed (the steps (6) and (7)), a method in which, after an electroplating layer is formed all over the thin film conductor layer, an etching process

is performed, is used to form the conductor circuits.

[0134]

If the through holes are formed in the steps (4) and (5), a resin filler may be filled into the through holes. In addition, if the resin filler is filled into the through holes, a cover plating layer which covers the surface portion of the resin filler layer may be formed by performing electroless plating as appropriate.

[0135]

(8) Subsequently, if the cover plating layer is formed, the surface of the cover plating layer is subjected to a roughening process, as appropriate, and, by repeating the steps (3) and (4), an interlayer resin insulation layer can be formed.

[0136]

(9) Thereafter, by repeating the steps (3) to (8) as appropriate, the conductor circuits and the interlayer resin insulation layers are formed on both sides of the multilayer interconnection board in a stacked manner. In this step, the through holes may be, but does not have to be, formed.

[0137]

By performing such steps (1) to (9), it is possible to produce the multilayer interconnection board in which the conductor circuits and the interlayer resin insulation layers are formed on both sides of the substrate in a stacked

manner. The process of producing the multilayer interconnection board described above in detail is a semi-additive method. However, the process of producing the multilayer interconnection board produced in the step (a) is not limited to the semi-additive method. A full-additive method, a subtractive method, a one-time lamination method, a conformal method or the like may also be used to produce the multilayer interconnection board. Among these methods, the additive methods, the semi-additive method and the full-additive method, are preferable. This is because these methods are suitable for forming a finer conductor circuits, and the flexibility in designing the conductor circuits are increased, because of their high etching precision.

[0138]

In the method of manufacturing an optical communication device of the fourth aspect of the present invention, after the multilayer interconnection board is produced through the step (a), the step (b), that is, the penetration-hole forming step of forming penetration holes in the multilayer interconnection board is performed. The penetration holes formed in this step serve as the light-signal transmitting optical path in the IC chip implementation substrate. For this reason, the penetration holes formed in this step are hereinafter also referred to as the optical-path penetration holes.

[0139]

The formation of the light-signal transmitting optical path is performed by drilling, a laser process or the like, for example. As the laser used in the laser process, a laser similar to that used in the formation of the via-hole openings can be named, for example. The locations at which the optical-path penetration holes are formed are not particularly limited, and may be selected as appropriate in consideration of the design of the conductor circuits, the positions at which the IC chips and the optical elements are implemented and the like. It is preferable that the optical-path penetration hole be formed for each optical element, such as the light receiving element and the light emitting element. The optical-path penetration hole may be formed for each signal wavelength. It is preferable that the diameter of the cross section of the optical-path penetration holes be from 100 to 500 μm. If the diameter is less than 100 μm, there is a possibility that the optical-path penetration hole is blocked. On the other hand, even if the diameter is larger than 500 μm, the transmission property of the light-signal transmitting optical path for the light signals would not be significantly improved, and the holes with this diameter can become a cause of the impairment of the flexibility in designing the conductor circuits and the like constituting the IC chip implementation substrate.

[0140]

After the optical-path penetration holes are formed, a desmear process may be performed to the wall surfaces of the optical-path penetration holes as appropriate. The desmear process can be performed using a permanganate solution treatment, a plasma treatment, a corona treatment or the like. By performing the desmear process, it is possible to remove resin residues, burrs and the like in the optical-path penetration holes.

[0141]

Subsequently, the step (c), that is, the metal-layer forming step of forming the glossy metal layer on the wall surfaces of the penetration holes (the optical-path penetration holes) is performed. It is preferable that, in the metal-layer forming step, the glossy metal layer be formed on the wall surfaces of the optical-path penetration holes, and, in addition, the conductor circuits be formed on the interlayer resin insulation layer which is the outermost layer. Consequently, description will be given below of a method in which the glossy metal layer is formed in the optical-path penetration holes, and, in addition, the conductor circuits are formed on the interlayer resin insulation layer which is the outermost layer.

[0142]

First, a conductor layer is formed on the wall

surfaces of the optical-path penetration holes, and is formed all over the surface of the interlayer resin insulation layer, by electroless plating or the like.

[0143]

Subsequently, a plating resist is formed all over the surface of conductor layer (except the part of the conductor layer formed on the wall surfaces of the optical-path penetration holes). The formation of the plating resist can be carried out by a method similar to that employed in the step (6) of the step (a), for example.

[0144]

Subsequently, electroplating, electroless plating or the like is performed to the conductor layer formed on the wall surfaces of the optical-path penetration holes, and the glossy metal layer is formed on the wall surfaces of the optical-path penetration holes. Thereafter, the plating resist is removed. As the material for the metal layer, gold, silver, nickel, platinum, aluminum, and rhodium can be named, for example.

[0145]

Subsequently, a plating resist is again formed on the conductor-circuit non-formed part (including the end face portions of the optical-path penetration holes) of the conductor layer formed on the surface of the interlayer resin insulation layer. The formation of the plating resist may be carried out by a method similar to that

employed in the step (6) of the step (a), for example.

[0146]

In addition, electroplating is performed using, as a plating bar, the conductor layer formed on the interlayer resin insulation layer, to thereby form an electroplating layer on the plating-resist non-formed part. Thereafter, the plating resist and the conductor layer under the plating resist are removed to thereby form separate conductor circuits on the interlayer resin insulation layer.

[0147]

As another method in which the glossy metal layer is formed on the wall surfaces of the optical-path penetration holes, and, in addition, the outermost conductor circuits are formed on the outermost interlayer resin insulation layer of the multilayer interconnection board, a method as described below may be used. Specifically, first, when the conductor layer is formed on the wall surfaces of the optical-path penetration holes by electroless plating or the like, the conductor layer is formed all over the surface of the interlayer resin insulation layer.

[0148]

Subsequently, a plating resist is formed on the conductor-circuit non-formed part of the conductor layer formed on the surface of the interlayer resin insulation layer. The formation of the plating resist may be carried out by a method similar to that employed in the step (6)

of the step (a), for example.

[0149]

In addition, electroplating is performed using, as a plating bar, the conductor layer formed on the wall surfaces of the optical-path penetration holes and on the interlayer resin insulation layer, to thereby form an electroplating layer on the wall surfaces of the optical-path penetration holes and on the plating-resist non-formed part. Thereafter, the plating resist and the conductor layer under the plating resist are removed to thereby form the glossy metal layer on the wall surfaces of the optical-path penetration holes, and, in addition, form separate conductor circuits on the interlayer resin insulation layer. With this method, it is possible to reduce the number of steps required to form the plating resist and the number of steps required to perform the electroplating. In this method, as the material for the electroplating layer formed on the conductor layer and in the optical-path penetration holes, gold, silver, nickel, platinum, or aluminum can be used. Accordingly, in this case, part of the conductor circuits are made of glossy metal.

[0150]

In the method of manufacturing an optical communication device of the fourth aspect of the present invention, the glossy metal layer formed in the

optical-path penetration holes, and the conductor circuits formed on the outermost, interlayer resin insulation layer may be formed separately. In this case, first, a plating resist is formed all over the surface of the multilayer interconnection board (except the wall surfaces of the optical-path penetration holes), and a conductor layer is then formed on the wall surfaces of the optical-path penetration holes by performing electroless plating. The formation of the plating resist may be carried out by a method similar to that employed in the step (6) of the step (a), for example. Thereafter, electroless plating or electroplating is performed to the conductor layer, to thereby form the glossy metal layer on the wall surfaces of optical-path penetration holes. As the material for the glossy metal layer, gold, silver, nickel, platinum, aluminum, and rhodium can be named, for example. Thereafter, by detaching the plating resist, it is possible to form the glossy metal layer on the wall surfaces of the optical-path penetration holes with the conductor layer interposed therebetween. The removal of the plating resist can be carried out using an alkaline aqueous solution or the like, for example. After the glossy metal layer is formed on the wall surfaces of the optical-path penetration holes in this way, the conductor circuits can be formed on the surface of the outermost, interlayer resin insulation layer by a process similar to that employed in

the steps (6) and (7) of the step (a). As the method of forming the glossy metal layer on the wall surfaces of the optical-path penetration holes, vacuum deposition, sputtering or the like can be used in addition to electroplating and electroless plating, for example.

[0151]

In the step (c), in the wall surface of the glossy metal layer formed on the wall surface of the optical-path penetration hole, a roughened surface may be formed as appropriate. As the method of forming the roughened surface, an etching process using an etchant containing cupric complex and organic salt, and a Cu-Ni-P needle-like alloy plating process can be named, for example. Alternatively, a roughened surface may be formed in a conductor layer after the conductor layer is formed by an electroless plating process or the like, and the glossy metal layer may be formed so as to follow the shape of the roughened surface. It should be noted that, after the roughened surface is formed in the conductor layer formed by an electroless plating process or the like, a glossy metal layer with a flat surface may be formed.

[0152]

It is preferable that, after the metal layer is formed in the penetration holes (the optical-path penetration holes) in the step (c), an uncured, resin composite be filled into the optical-path penetration holes. If the uncured,

resin composite is filled into the optical-path penetration holes, and then subjected to a curing process, it is possible to provide the light-signal transmitting optical path in which the optical-path resin layer is formed. The method of filling the uncured, resin composite is not particularly limited. A printing method, a potting method or the like can be used, for example. If the filling of the uncured, resin composite is performed by printing, the uncured, resin composite may be filled in one step, or the printing may be performed in two or more steps. The printing may also be performed from both sides of the multilayer interconnection board.

[0153]

When the filling of the uncured, resin composite is performed, the uncured, resin composite a bit larger in volume than the optical-path penetration holes may be filled thereinto, and, after the filling has been completed, the excess resin composite spilling out of the optical-path penetration holes may be removed. The removal of the excess resin composite can be carried out by polishing or the like, for example. When the excess resin composite is removed, the state of the resin composite may be either a semi-cured state or a fully cured state, and can be selected therefrom as appropriate in consideration of the composition of the resin composite and the like. As the uncured, resin composite, those similar to the material for the

optical-path resin layer described in relation to the IC chip implementation substrate constituting the optical communication device of the first aspect of the present invention, can be named, for example.

[0154]

Through the penetration-hole forming step, the metal-layer forming step, and the resin-composite filling step performed as appropriate, which are described above, in the multilayer interconnection board produced through the step (a), the resin composite is filled into the inside thereof, and, in addition, the part of the light-signal transmitting optical paths on the surrounding wall surfaces of which the metal layer is formed, which part passes through the substrate and the interlayer resin insulation layer, can be formed. Moreover, when the metal-layer forming step is performed, if the conductor layer is formed on the surface of the interlayer resin insulation layer, and the above-described process is carried out, the separate conductor circuits can be formed.

[0155]

Subsequently, a solder-resist-layer forming step of forming a solder resist layer having openings which communicate with the penetration holes (the optical-path penetration holes) formed in the step (b), is performed as appropriate. Specifically, the solder resist layer can be formed by performing steps (1) and (2) described below,

for example.

[0156]

(1) First, a layer of a solder resist composite is formed on the outermost layer of the multilayer interconnection board in which the optical-path penetration holes are formed. The solder resist composite layer can be formed using a solder resist composite containing polyphenylene ether resin, polyolefin resin, fluororesin, thermoplastic elastomer, epoxy resin, polyimide resin or the like.

[0157]

As the solder resist composite other than the above-mentioned ones, a paste-like fluid containing thermosetting resin containing (meth)acrylate of novolac type epoxy resin, an imidazole curing agent, a bifunctional (meth)acrylic ester monomer, a (meth)acrylic ester polymer with a molecular weight of about 500 to 5000, bisphenol type epoxy resin and the like; a photosensitive monomer, such as a multivalent acrylic monomer; and a glycol ether type solvent can be named, for example. It is preferable that the viscosity thereof be adjusted to be from 1 to 10 Pa·s at 25°C. A solder resist composite on the market may also be used. In this step, the solder resist composite layer may be formed by pressure lamination of a film made of the above-named solder resist composite.

[0158]

(2) Subsequently, openings (hereinafter also referred to

as the optical-path openings) communicating with the optical-path penetration holes are formed in the solder resist composite layer. Specifically, the openings are formed by a method similar to that of forming the via-hole openings, that is, by an exposure and development process, or a laser process. It is preferable that, when the optical-path openings are formed, solder-bump forming openings (openings for implementing the IC chips or the optical elements, or openings for connection with an external board such as a multilayer printed wiring board) be formed at the same time. The formation of the optical-path openings and the formation of the solder-bump forming openings may be performed separately.

[0159]

When the solder resist layer is formed, the solder resist layer having the optical-path openings and the solder-bump forming openings may be formed by preparing a resin film having openings at predetermined locations in advance, and then laminating the resin film. Through the steps (1) and (2) as described above, it is possible to form the solder resist layer having the openings communicating with the optical-path penetration holes, on the multilayer interconnection board in which the optical-path penetration holes are formed. It should be noted that the diameter of the optical-path openings may be the same as that of the optical-path penetration holes,

or may be smaller than that of the optical-path penetration holes.

[0160]

If the optical-path resin layer is formed in the optical-path penetration holes after the step (c), it is preferable that, also in this step, an uncured, resin composite be filled into the optical-path openings formed in the solder resist layer, and the optical-path resin layer be formed by performing a curing process. If the optical-path resin layer is formed also in this step, the optical-path resin layer is formed throughout the inside of the light-signal transmitting optical path. It is preferable that the uncured, resin composite filled into the optical-path openings be the same as that filled into the optical-path penetration holes described above.

[0161]

If formed is the light-signal transmitting optical path throughout the inside of which the optical-path resin layer is formed, instead of the filling of the uncured, resin composite after the step (c), an uncured, resin composite may be filled into the optical-path penetration holes and the optical-path openings communicating therewith in this step, and thereafter, a curing process may be performed, to thereby obtain the light-signal transmitting optical path throughout the inside of which the optical-path resin layer is formed.

[0162]

Alternatively, the optical-path resin layer may be formed in a following way. In the step (c), an uncured, resin composite is filled into the optical-path penetration holes, and thereafter, the resin composite is semi-cured. Subsequently, the solder resist layer having the optical-path openings is formed by the method described above. After an uncured, resin composite is filled into the optical-path openings, the resin composite in the optical-path penetration holes and the resin composite in the optical-path openings are subjected to a curing process at once.

[0163]

A microlens is disposed at an end of the light-signal transmitting optical path as appropriate. In order to dispose a microlens at an end of the light-signal transmitting optical path, the microlens may be disposed at the end of the light-signal transmitting optical path via an adhesive layer formed on the solder resist layer. Especially, if the optical-path resin layer is formed in the light-signal transmitting optical path, it is preferable to directly dispose the microlens on the optical-path resin layer.

[0164]

As the method of directly disposing the microlens on the optical-path resin layer, a method in which a proper

amount of uncured, optical-lens resin is dripped on the optical-path resin layer, and the uncured, optical-lens resin thus dripped is subjected to a curing process, can be named, for example. When the proper amount of uncured, optical-lens resin is dripped on the optical-path resin layer, a device, such as a dispenser, an inkjet device, a micropipet, a microsyringe or the like can be used. The uncured, optical-lens resin dripped on the optical-path resin layer via such a device tends to be a spherical shape due to the surface tension, and therefore takes a hemispherical shape on the optical-path resin layer. By thereafter subjecting the hemispherical, uncured, optical-lens resin to the curing process, it is possible to dispose a hemispherical microlens on the optical-path resin layer.

[0165]

As the uncured, optical-lens resin, a resin similar to that described in relation to the optical communication device of the first aspect of the present invention can be named. It should be noted that the diameter, the shape of the curved surface, and others of the microlens formed by the above-described method can be controlled by adjusting the viscosity and others of the uncured, optical-lens resin as appropriate, in consideration of the wettability between the resin composite and the uncured, optical-lens resin.

[0166]

The part of the conductor circuits exposed as a result of the formation of the solder-bump forming openings and the like are covered with corrosion-resistant metal, such as nickel, palladium, gold, silver and platinum to thereby obtain solder pads as appropriate. Among the corrosion resistant metals, it is preferable to form a cover layer out of metal, such as nickel-gold, nickel-silver, nickel-palladium, nickel-palladium-gold and the like. The coating layer can be formed by plating, vapor deposition, electrodeposition or the like, for example. Among them, it is preferable that plating be used to form the cover layer because the cover layer will have excellent evenness.

[0167]

After solder paste is filled into the solder pads via a mask in which openings are formed in the areas corresponding to the openings for implementing the IC chips (IC-chip implementing openings) and the openings for connection with an external board such as a multilayer printed wiring board (multilayer-interconnection-board connecting openings), solder bumps are formed by reflow. If such solder bumps are formed, it is possible to implement IC chips and to establish connection with an external board such as a multilayer printed wiring board via the solder bumps. The solder bumps may be formed as appropriate. Even if no solder bumps are formed, via the bumps of the IC chips

to be implemented or those of the external board such as the multilayer interconnection board, these objects and the IC chip implementation substrate can be electrically connected.

[0168]

Subsequently, the step (d), that is, the optical-element implementing step of implementing the optical elements at such positions that light signals can be transmitted via the openings (the optical-path openings) and the penetration holes (optical-path penetration holes), is performed.

[0169]

With regard to the implementation of the optical elements, for example, in the step of filling the solder paste into the openings for implementing the IC chips and other openings, the solder paste is also filled into the openings (the optical-element implementing openings) for implementing the optical elements, and, when the reflow is performed, the optical elements may be mounted for implementation via the solder. Alternatively, instead of using the solder paste, the optical elements may be implemented via electrically conductive adhesive agent or the like. As the optical elements, the light receiving elements and the light emitting elements mentioned above can be named, for example. Through such steps, it is possible to produce the IC chip implementation substrate.

[0170]

Description will now be given of the process of producing the multilayer printed wiring board.

(1) First, conductor circuits are formed on both sides of a substrate, and, in addition, through holes for connecting the conductor circuits between which the substrate is sandwiched are formed by a process similar to that employed in the steps (1) and (2) of the step (a). Also in this step, roughened surfaces are formed in the surfaces of the conductor circuits and the wall surfaces of the through holes as appropriate.

[0171]

(2) Subsequently, an interlayer resin insulation layer and conductor circuits are formed, in a stacked manner, on the substrate on which the conductor circuits have been formed as appropriate. Specifically, first, an interlayer resin insulation layer having via-hole openings is formed by a process similar to that employed in the steps (3) and (4) of the step (a) of the process of producing the IC chip implementation substrate. Thereafter, a thin film conductor layer is formed on the surface of the interlayer resin insulation layer including the wall surfaces of the via-hole openings by a process similar to that employed in the step (5) of the process of producing the IC chip implementation substrate.

[0172]

Subsequently, the thickness of the conductor layer is increased by forming an electroplating layer and the like all over the thin film conductor layer. The formation of the electroplating layer and the like may be carried out as appropriate. Subsequently, an etching resist is formed on the conductor layer. The etching resist is formed by, for example, laminating a photosensitive dry film, closely arranging a photomask over the photosensitive dry film, and performing an exposure and development process.

[0173]

Thereafter, the conductor layer under the etching-resist non-formed part is removed by an etching process, and then the etching resist is detached, to thereby form the conductor circuits (including via holes) on the interlayer resin insulation layer. For example, the etching process can be performed using an etchant containing a solution mixture of sulfuric acid and hydrogen peroxide, sodium persulfate, ammonium persulfate, ferric chloride, cupric chloride or the like. The detaching of the etching resist can be carried out using an alkaline aqueous solution or the like.

[0174]

Although the method of forming the conductor circuits described above is a subtractive method, as the method of forming the conductor circuits on the interlayer resin insulation layer, a process similar to that employed in

the steps (5) to (7) of the step (a) of the process of producing the IC chip implementation substrate may be used to form the conductor circuits. In addition, the step (2), that is, the step of stacking the interlayer resin insulation layer and the conductor circuits may be performed once, or may be performed plural number of times.

[0175]

(3) Subsequently, optical waveguides are formed on the substrate on the side thereof facing the IC chip implementation substrate, or formed on the conductor-circuit non-formed part of the interlayer resin insulation layer. If inorganic material, such as silica glass, is used as the material for the optical waveguides, the formation of the optical waveguides can be carried out by attaching, via an adhesive agent, optical waveguides which are formed in a predetermined shape beforehand. The optical waveguides made of inorganic material can be formed by depositing inorganic material, such as $LiNbO_3$ and $LiTaO_3$, by liquid phase epitaxy, chemical vapor deposition (CVD), molecular beam epitaxy or the like.

[0176]

If the optical waveguides are formed using polymer material, the optical waveguides can be formed by laminating an optical-waveguide forming film onto the interlayer resin insulation layer, which film has been formed on a substrate or on a mold-releasing film beforehand,

or by directly forming the optical waveguides on the interlayer resin insulation layer. Specifically, the optical waveguides can be formed by a method using reactive ion etching, an exposure and development method, a mold formation method, a resist formation method, a combination of these methods or the like. It should be noted that these methods can be used either when optical waveguides are formed on the substrate or the mold-releasing film, or when the optical waveguides are directly formed on the interlayer resin insulation layer.

[0177]

With regard to the method using reactive ion etching, (i) first, a lower cladding is formed on the mold-releasing film or the like, and then, (ii) a core resin composite is applied onto the lower cladding, and, as appropriate, a curing process is performed, to thereby obtain a core forming resin layer. (iii) Subsequently, a mask forming resin layer is formed on the core forming resin layer, and this mask forming resin layer is subjected to an exposure and development process, to thereby form a mask (an etching resist) on the core forming resin layer.

[0178]

(iv) Subsequently, the core forming resin layer is subjected to reactive ion etching, to thereby remove the core forming resin layer of the mask non-formed part, and form the core on the lower cladding. (v) Finally, an upper

cladding is formed over the lower cladding so as to cover the core, to thereby obtain the optical waveguides. When the method using reactive ion etching is used, it is possible to form optical waveguides excellent in dimension reliability. In addition, this method is excellent in reproducibility.

[0179]

With regard to the exposure and development method, (i) first, a lower cladding is formed on the mold-releasing film or the like, and then, (ii) a core resin composite is applied onto this lower cladding, and, as appropriate, a semi-curing process is performed, to thereby form a layer made of the core forming resin composite.

[0180]

(iii) Subsequently, a mask on which a pattern corresponding to a core formation portion is drawn is put on the layer of the core-layer forming resin composite, and an exposure and development process is then performed, to thereby form a core on the lower cladding. (v) Finally, an upper cladding is formed over the lower cladding so as to cover the core, to thereby obtain the optical waveguides. Since this exposure and development method requires a small number of steps, it can be suitably used when mass-producing the optical waveguides. In addition, since this method requires a small number of heating steps, stress is less prone to occur in the optical waveguide.

[0181]

With regard to the mold formation method, (i) first, a lower cladding is formed on the mold-releasing film or the like, and then (ii) a core forming groove is formed in the lower cladding by mold formation. (iii) A core resin composite is filled into the groove by printing, and then, a curing process is performed to thereby form the core. (iv) Finally, an upper cladding is formed over the lower cladding so as to cover the core, to thereby obtain optical waveguides. This mold formation method can be suitably used when mass-producing the optical waveguides, and it is possible to form the optical waveguides excellent in dimension reliability. In addition, this method is excellent in reproducibility.

[0182]

With regard to the resist formation method, (i) first, a lower cladding is formed on a mold-releasing film or the like, and then, (ii) a resist resin composite is applied onto this lower cladding, and an exposure and development process is performed, to thereby form a core forming resist on the core non-formed part of the lower cladding.

[0183]

(iii) Subsequently, a core resin composite is applied onto the resist non-formed part of the lower cladding. (iv) The core resin composite is cured, and then, the core forming resist is detached, to thereby form a core on the lower

cladding. (v) Finally, an upper cladding is formed over the lower cladding so as to cover the core, to thereby obtain the optical waveguides. This resist formation method can be suitably used when mass-producing optical waveguides, and the optical waveguides excellent in dimension reliability can be formed. In addition, this method is excellent in reproducibility. It should be noted that, with regard to the optical waveguides formed by these methods, the refractive index of the core is set higher than the refractive index of the claddings.

[0184]

When the optical waveguides are formed in this step, if the optical waveguides are directly formed on the substrate or the interlayer resin insulation layer by the method as described above in which the lower cladding, the core, and the upper cladding are formed by sequentially stacking them, and if the upper cladding is formed all over the substrate or the interlayer resin insulation layer in this case, the upper cladding can serve as the solder resist layer. Alternatively, if the lower cladding and the core are formed in a film beforehand, this is laminated onto the substrate or the interlayer resin insulation layer in a predetermined position, and then, the upper cladding is formed all over the substrate or the interlayer resin insulation layer, the upper cladding can serve as the solder resist layer.

[0185]

In the optical waveguides, optical-path changing mirrors are formed. The optical-path changing mirrors may be formed before the optical waveguides are attached to the interlayer resin insulation layer, or may be formed after the optical waveguides are attached to the interlayer resin insulation layer. However, it is preferable that the optical-path changing mirrors be formed beforehand, except in the case where the optical waveguides are directly formed on the interlayer resin insulation layer. This is because the work can be easily done, and because there is no fear that the substrate, the conductor circuits, the interlayer resin insulation layer and the like, which constitute the multilayer printed wiring board, are scratched or damaged while at work.

[0186]

The method of forming the optical-path changing mirrors is not particularly limited, and forming methods which have been publicly known can be used. Specifically, machining using a diamond saw having a 90° V-shaped tip or an edge tool, processing by reactive ion etching, laser abrasion, or the like can be used.

[0187]

(4) Subsequently, a solder resist layer is formed on the outermost layer of the substrate on which the optical waveguides are formed, as appropriate. The solder resist

layer can be formed using a resin composite similar to that used in forming the solder resist layer of the IC chip implementation substrate, for example.

[0188]

(5) Subsequently, solder-bump forming openings (the openings for implementing the IC chip implementation substrate or various surface-mount type electronic components) and optical-path openings are formed in the solder resist layer on the side facing the IC chip implementation substrate. The formation of the solder-bump forming openings and the optical-path openings can be carried out by a method similar to that of forming the solder-bump forming openings in the IC chip implementation substrate, that is, an exposure and development process, a laser process or the like. It should be noted that the formation of the solder-bump forming openings and the formation of the optical-path openings may be performed at the same time, or may be performed separately.

[0189]

Among these methods, it is preferable to select a method in which, when the solder resist layer is formed, a resin composite containing photosensitive resin is applied as the material therefor, and then, an exposure and development process is performed to thereby form the solder-bump forming openings and the optical-path openings.

This is because, if the optical-path openings are formed by the exposure and development process, there is no fear of scratching the optical waveguides present under the optical-path openings at the time of forming the openings. Alternatively, when the solder resist layer is formed, the solder resist layer having the solder-bump forming openings and the optical-path openings may be formed by preparing a resin film having openings at desired locations in advance, and then laminating the resin film.

[0190]

The solder-bump forming openings may also be formed in the solder resist layer on the opposite side from the side facing the IC chip implementation substrate, as appropriate. This is because, through later steps, it is possible to form external connection terminals also in the solder resist layer on the opposite side from the side facing the IC chip implementation substrate.

[0191]

(6) The part of the conductor circuits, which are exposed as a result of the formation of the solder-bump forming openings, are coated with corrosion resistant metal, such as nickel, palladium, gold, silver and platinum, as appropriate, to thereby form solder pads. Specifically, this may be carried out by a method similar to that described in relation to the process of producing the IC chip implementation substrate.

[0192]

(7) Subsequently, an uncured, resin composite is filled into the optical-path openings formed in the step (5), as appropriate, and is then subjected to a curing process to thereby form the optical-path resin layer. It is preferable that the uncured, resin composite filled in this step be the same as that filled into the optical-path penetration holes and the optical-path openings in the production process of the IC chip implementation substrate.

[0193]

(8) Subsequently, after solder paste is filled into the solder pads via a mask in which openings are formed in the areas corresponding to the solder pads, solder bumps are formed by reflow. If such solder bumps are formed, it is possible to implement the IC chip implementation substrate or various surface-mount type electronic components via the solder bumps. The solder bumps may be formed as appropriate. Even if no solder bumps are formed, it is possible to, via the bumps of the IC chip implementation substrate or various surface-mount type electronic components to be implemented, implement them. With regard to the solder resist layer on the opposite side from the side facing the IC chip implementation substrate, the external connection terminals do not have to be formed in particular. Instead, by arranging pins or forming solder balls, the PGA (Pin Grid Array) or the BGA (Ball Grid Array)

may be provided. Through such steps, it is possible to produce the multilayer printed wiring board constituting the optical communication device.

[0194]

In the method of manufacturing an optical communication device of the fourth aspect of the present invention, subsequently, the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions that light signals can be transmitted between the optical elements of the IC chip implementation substrate and the optical waveguides of the multilayer printed wiring board via the light-signal transmitting optical paths. In this embodiment, after the IC chip implementation substrate and the multilayer printed wiring board are placed so as to face each other, solder connections are formed using the solder bumps of the IC chip implementation substrate and the solder bumps of the multilayer printed wiring board, to thereby electrically connect and fix both of them. Specifically, the IC chip implementation substrate and the multilayer printed wiring board are placed so as to face each other in predetermined positions and in predetermined orientations, and connected by reflow. It should be noted that the solder bumps for fixing both of the IC chip implementation substrate and the multilayer printed wiring board may be formed on one of them.

[0195]

In this step, since the IC chip implementation substrate and the multilayer printed wiring board are connected using their solder bumps, even if there is slight misalignment between the IC chip implementation substrate and the multilayer printed wiring board when both of these are placed so as to face each other, it is possible to place both of them in predetermined positions by virtue of the self-alignment effect of solder at the time of reflow.

[0196]

In manufacturing methods of the present invention, after the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in predetermined positions, a sealing resin composite may be poured between the IC chip implementation substrate and the multilayer printed wiring board, and then, a curing process may be performed to thereby form a sealing resin layer.

[0197]

As the sealing resin composite, those in which a curing agent, various addition agents, a solvent and/or the like are appropriately mixed, in addition to resin components, such as acrylic resin, such as PMMA (polymethyl methacrylate), deuterated PMMA, as well as deuterated and fluorinated PMMA; polyimide resin, such as fluorinated polyimide; epoxy resin; UV-curing epoxy resin; silicone

resin, such as deuterated silicone resin; and polymers produced from benzocyclobutene, and particles which are contained as appropriate, can be named, for example. It is preferable that the sealing resin composite have a transmittance of 70% or more for the light at the communication wavelength after curing.

[0198]

Here, the viscosity of the sealing resin composite which is poured between the IC chip implementation substrate and the multilayer printed wiring board, and curing conditions under which the curing process is performed after the sealing resin composite is poured therebetween, can be appropriately selected in consideration of the composition of the sealing resin composite, the design of IC chip implementation substrate and the multilayer printed wiring board, and others.

[0199]

Subsequently, IC chips are implemented on the IC chip implementation substrate, and then, resin sealing of the IC chips are performed as appropriate, to thereby obtain the optical communication device. The implementation of the IC chips can be performed by a publicly known method. Alternatively, the implementation of the IC chips may be performed before the IC chip implementation substrate and the multilayer printed wiring board are connected, and then, the IC chip implementation substrate on which the IC chips

have been implemented and the multilayer printed wiring board may be connected to thereby obtain the optical communication device.

[0200]

Description will now be given of an optical communication device of the second aspect of the present invention. The optical communication device of the second aspect of the present invention is an optical communication device including an IC chip implementation substrate and a multilayer printed wiring board, characterized in that the multilayer printed wiring board includes a substrate and a conductor circuit, and has a light-signal transmitting optical path disposed therein which passes through at least the substrate, and that the light-signal transmitting optical path has a glossy metal layer formed on part of or all over a wall surface of the light-signal transmitting optical path.

[0201]

With regard to the optical communication device of the second aspect of the present invention, since the glossy metal layer formed on part of or all over the wall surface of the light-signal transmitting optical path can favorably reflect the light signal transmitted in the light-signal transmitting optical path, the light signal is less prone to be attenuated or absorbed when impinging on the wall surface of the light-signal transmitting optical path.

Accordingly, with the optical communication device of the second aspect of the present invention, since the loss of the light signal transmitted in the light-signal transmitting optical path is less prone to occur, the optical communication device is excellent in the light-signal transmission reliability, making it possible to realize reliable optical communication.

[0202]

In the optical communication device of the second aspect of the present invention, a light-signal transmitting optical path passing through at least the substrate is disposed in the multilayer printed wiring board constituting the optical communication device. In the multilayer printed wiring board having such a light-signal transmitting optical path disposed therein, it is possible to transmit light signals via the light-signal transmitting optical path.

[0203]

In the optical communication device of the second aspect of the present invention, the light-signal transmitting optical path has a glossy metal layer formed on part of or all over the wall surface thereof. If the glossy metal layer is formed on part of or all over the wall surface of the light-signal transmitting optical path in this way, when the light signal transmitted in the light-signal transmitting optical path impinges on the wall

surface of the light-signal transmitting optical path, the light signal is favorably reflected by the glossy metal layer, so that the loss of the light signal is less prone to occur, and it is possible to improve the light-signal transmission reliability. Although the glossy metal layer is formed on part of the wall surface of the light-signal transmitting optical path, or is formed all over the wall surface thereof, if the glossy metal layer is formed on part of the wall surface of the light-signal transmitting optical path, it is preferable that the glossy metal layer be formed on the wall surface of the part of the light-signal transmitting optical path, which part passes through the substrate and the interlayer resin insulation layer. This is because, normally, the substrate and the interlayer resin insulation layer have high adhesion to metal, and a solder resist layer has low adhesion to metal.

[0204]

In addition, it is preferable that the light-signal transmitting optical path include a cavity. If the light-signal transmitting optical path includes a cavity, the formation thereof is easy, and the transmission loss is less prone to occur in transmitting the light signal via the light-signal transmitting optical path. Whether or not to make the constitution of the light-signal transmitting optical path include a cavity may be appropriately decided in consideration of the thickness

of the multilayer printed wiring board or the like.

[0205]

It is also preferable that the light-signal transmitting optical path include a resin composite. If the light-signal transmitting optical path includes the resin composite, the reduction in strength of the multilayer printed wiring board can be prevented. In addition, if the light-signal transmitting optical path is comprised of the resin composite, it is possible to prevent dust, contaminants or the like from entering into the light-signal transmitting optical path, accordingly, it is possible to prevent the transmission of light signals from being impeded due to the existence of the dust, contaminants or the like.

[0206]

It is also preferable that the light-signal transmitting optical path include a resin composite and a cavity. If the light-signal transmitting optical path includes the resin composite and the cavity, it is possible to prevent the reduction in strength of the multilayer printed wiring board. If the light-signal transmitting optical path includes the resin composite and the cavity, it is preferable that the light-signal transmitting optical path formed in the part passing through the substrate and the interlayer resin insulation layer be comprised of the resin composite, and the light-signal transmitting optical

path formed in the solder resist layer be comprised of the cavity. This is because, normally, the substrate and the interlayer insulation layer have high adhesion to resin, and the solder resist layer has low adhesion to resin.

[0207]

The IC chip implementation substrate constituting the optical communication device is not particularly limited. The IC chip implementation substrate constituting the optical communication device of the first aspect of the present invention can be named, for example. In the IC chip implementation substrate constituting the optical communication device of the second aspect of the present invention, the light-signal transmitting optical path does not have to be formed. If optical elements, such as light receiving elements and light emitting elements, are implemented on the IC chip implementation substrate, the elements may be mounted on the IC chip implementation substrate on the side thereof facing the multilayer printed wiring board via solder, electrically conductive agents, or the like. In this case, even if no light-signal transmitting optical paths are formed in the IC chip implementation substrate, it is possible to transmit light signals between either the light receiving element or the light emitting element and the optical waveguides formed in the multilayer printed wiring board.

[0208]

Description will be given below of the optical communication device of the second aspect of the present invention with reference to the drawings. Fig. 3 is a cross-sectional view schematically showing an embodiment of the optical communication device of the second aspect of the present invention. In Fig. 3, there is shown the optical communication device with an IC chip implemented thereon.

[0209]

As shown in Fig. 3, the optical communication device 350 of the second aspect of the present invention is comprised of: the IC chip implementation substrate 320 on which the IC chip 340 is implemented; and the multilayer printed wiring board 300. The IC chip implementation substrate 320 and the multilayer printed wiring board 300 are electrically connected via solder connections 341.

[0210]

In the IC chip implementation substrate 320, conductor circuits 324 and interlayer insulation layers 322 are formed on both sides of a substrate 321 in a stacked manner. In addition, the conductor circuits between which the substrate 321 is sandwiched, and the conductor circuits between which the interlayer insulation layer 322 is sandwiched are electrically connected using through holes 329, and via holes 327, respectively. As the outermost layers of the IC chip implementation substrate 320, solder

resist layers 334 provided with solder bumps are formed. In addition, the outermost layer on the side facing the multilayer printed wiring board 300 is provided with a light receiving element 338 and a light emitting element 339 in such a manner that a light receiving portion 338a and a light emitting portion 339a are individually exposed.

[0211]

In the multilayer printed wiring board 300, conductor circuits 304 and interlayer insulation layers 302 are formed on both sides of a substrate 301 in a stacked manner. In addition, the conductor circuits between which the substrate 301 is sandwiched, and the conductor circuits between which the interlayer insulation layer 302 is sandwiched are electrically connected using through holes 309, and via holes 307, respectively. In the multilayer printed wiring board 300, light-signal transmitting optical paths 361 passing through the substrate 301, the interlayer resin insulation layer 302, and a solder resist layer 314 are formed, so that the multilayer printed wiring board 300 is constructed so as to be able to transmit light signals between optical waveguides 319 (319a, 319b), and the light receiving element 338 and the light emitting element 339 via the light-signal transmitting optical paths 361. In addition, the light-signal transmitting optical path 361 has a metal layer 361b formed on part of the wall surface thereof, and has an optical-path resin layer 361a

formed in part of the inside thereof. In the multilayer printed wiring board 300, the optical waveguides 319 are formed on the interlayer resin insulation layer 302 which is the outermost layer on the opposite side from the side facing the IC chip implementation substrate 320 with respect to the substrate 301. The optical waveguides 319 are provided with optical-path changing mirrors 319 (319a, 319b). With regard to the optical communication device 350 shown in Fig.3, the light receiving element and the light emitting element are implemented on the side facing the multilayer printed wiring board.

[0212]

Since such an optical communication device of the second aspect of the present invention performs optical/electric signal conversion in the IC chip implementation substrate, that is, near the IC chip, the transmission distance of the electric signals is short, and it is therefore possible to deal with high speed communication more favorably. In addition, the electric signals sent from the IC chip are not only sent out to the outside via optical fibers after converted into the light signals as described above, but also sent to the multilayer printed wiring board via the solder connections, and then sent to the electronic components such as other IC chips implemented on the multilayer printed wiring board, via conductor circuits (including via holes and through holes)

in the multilayer printed wiring board. With regard to the optical communication device having such a construction, since the misalignment of the light receiving elements and the light emitting elements implemented on the IC chip implementation substrate, as well as the optical waveguides formed in the multilayer printed wiring board is less prone to occur, the connection reliability concerning light signals is excellent.

[0213]

It should be noted that, although the positions where the optical waveguides are formed in the multilayer printed wiring board shown in Fig. 3 are on the interlayer insulation layer which is the outermost layer, the positions where the optical waveguides are formed in the multilayer printed wiring board constituting the optical communication device of the second aspect of the present invention are not limited to the positions. The positions may be between interlayer insulation layers, or may be on the substrate.

[0214]

In addition, in the multilayer printed wiring board 300 shown in Fig. 3, the glossy metal layer 361b is formed on the surface of the wall surrounding the part of the light-signal transmitting optical path 361, which part passes through the substrate 301 and the interlayer resin insulation layer 302. Since the glossy metal layer is formed on the wall surfaces of the light-signal

transmitting optical paths in this way, the optical communication device of the second aspect of the present invention comes to be such that, when light signals are transmitted in the light-signal transmitting optical path, the light signals are favorably reflected by the metal layer, and the loss of the light signals is therefore less prone to occur, so the optical communication device is excellent in the signal transmission reliability. Although, in the multilayer printed wiring board 300 shown in Fig. 3, the metal layer 361b is formed in part of the light-signal transmitting optical path 361 (the part passing through the substrate 301 and the interlayer resin insulation layer 302), the IC chip implementation substrate constituting the optical communication device of the second aspect of the present invention may have a structure in which the metal layer is formed all over the wall surface of the light-signal transmitting optical path.

[0215]

Since the materials for the light-signal transmitting optical paths, the optical elements, the optical waveguides and others, and the like in the optical communication device of the second aspect of the present invention are similar to those of the optical communication device of the first aspect of the present invention, description thereof is omitted. The optical communication device of the second aspect of the present invention having

such a construction can be manufactured by the method of manufacturing an optical communication device of the fifth aspect of the present invention to be described later, for example.

[0216]

Description will now be given of the method of manufacturing an optical communication device of the fifth aspect of the present invention. The method of manufacturing an optical communication device of the fifth aspect of the present invention is characterized in that, after an IC chip implementation substrate on which an optical element is implemented is produced, and, separately, a multilayer printed wiring board is produced by a process including: (A) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (B) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (C) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (D) an optical-waveguide forming step of forming an optical waveguide at such a position that a light signal can be transmitted via the penetration hole, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to

each other in such positions that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[0217]

With regard to the multilayer printed wiring board constituting the optical communication device manufactured by the method of manufacturing an optical communication device of the fifth aspect of the present invention, the glossy metal layer is formed on part of or all over the light-signal transmitting optical path, and the metal layer can favorably reflect the light signal transmitted in the light-signal transmitting optical path. Accordingly, since the light signal is less prone to be attenuated or absorbed when impinging on the wall surface of the light-signal transmitting optical path, and the loss of the light signal transmitted in the light-signal transmitting optical path is therefore less prone to occur, the optical communication device is excellent in the light-signal transmission reliability, making it possible to realize reliable optical communication. Accordingly, with the method of manufacturing an optical communication device of the fifth aspect of the present invention, it is possible to manufacture an optical communication device in which the connection loss between the implemented optical components is low, and which is excellent in the

connection reliability.

[0218]

The optical communication device of the fifth aspect of the present invention can also be manufactured by producing the IC chip implementation substrate and the multilayer printed wiring board separately, and then connecting both of them via solder or the like, as in the case of the method of manufacturing an optical communication device of the fourth aspect of the present invention. Accordingly, in relation to this embodiment, description will first be given of respective processes of producing the IC chip implementation substrate and the multilayer printed wiring board separately, and description will then be given of a method of connecting both of them.

[0219]

As the process of producing the IC chip implementation substrate, a process similar to that of producing the IC chip implementation substrate in the method of manufacturing an optical communication device of the fourth aspect of the present invention, can be used, for example. As described above, with regard to the method of manufacturing an optical communication device of the fifth aspect of the present invention, the IC chip implementation substrate may have no light-signal transmitting optical paths disposed therein. If the IC chip implementation

substrate in which no light-signal transmitting optical paths are formed is produced, optical-element implementing openings may be formed as appropriate, instead of performing either the step (b) or the formation of the optical-path openings in the step (c), in the process of producing the IC chip implementation substrate in the method of manufacturing an optical communication device of the fifth aspect of the present invention, for example. When the IC chip implementation substrate is formed, the formation of a solder resist layer may be performed as appropriate.

[0220]

As the process of producing the multilayer printed wiring board, a process in which the following steps (1) to (5) are performed can be used, for example.

(1) The multilayer interconnection board in which optical-path penetration holes are formed is produced by a process similar to that employed in the steps (a) and (b) of the process of producing the IC chip implementation substrate in the method of manufacturing an optical communication device of the fourth aspect of the present invention.

[0221]

(2) Subsequently, optical waveguides are formed on the conductor-circuit non-formed part of the interlayer insulation layer of the multilayer interconnection board.

The optical waveguides are formed at such positions that light signals can be transmitted via the optical-path penetration holes. As a specific method of forming the optical waveguides, a method similar to that employed in the step (3) of the process of producing the multilayer printed wiring board in the method of manufacturing an optical communication device of the fourth aspect of the present invention, can be used, for example. In the optical waveguides formed in this step, optical-path changing mirrors are formed.

[0222]

(3) Subsequently, a solder resist layer is formed on the outermost layer of the multilayer interconnection board in which the optical waveguides are formed. The solder resist layer may be formed by a process similar to that employed in the step (4) of the process of producing the multilayer printed wiring board in the method of manufacturing an optical communication device of the fourth aspect of the present invention, for example. The formation of a solder resist layer may be performed as appropriate.

[0223]

(4) Subsequently, solder-bump forming openings and optical-path openings are formed in the solder resist layer on the side facing the IC chip implementation substrate. The solder-bump forming openings and the optical-path

openings may be formed by a method similar to that employed in the step (5) of the process of producing the multilayer printed wiring board in the method of manufacturing an optical communication device of the fourth aspect of the present invention, for example. The optical-path openings are formed so as to communicate with the optical-path penetration holes formed in the step (1). In this step, after the optical-path openings are formed, a resin composite may be filled into the optical-path openings. As the resin composite, one similar to that filled into the optical-path penetration holes in the step (1) can be named, for example. In this step, the resin composite may be filled into the optical-path penetration holes and the optical-path openings at the same time.

[0224]

(5) Subsequently, solder pads, solder bumps and the like are formed by, for example, a method similar to that employed in the steps (6) to (8) of the process of producing the multilayer printed wiring board in the method of manufacturing an optical communication device of the fourth aspect of the present invention, whereby the multilayer printed wiring board can be produced.

[0225]

Subsequently, the IC chip implementation substrate and the multilayer printed wiring board produced by the above-described processes are connected to thereby

manufacture the optical communication device. Specifically, this may be carried out by a method similar to that employed for manufacturing an optical communication device of the fourth aspect of the present invention. As in the case of manufacturing an optical communication device of the fourth aspect of the present invention, with regard to the IC chip implementation substrate and the multilayer printed wiring board, the solder bumps may be formed on one of the surfaces facing each other. This is because, also in this case, both of the IC chip implementation substrate and the multilayer printed wiring board can be connected.

[0226]

Description will now be given of an optical communication device of the third aspect of the present invention. The optical communication device of the third aspect of the present invention is characterized in that the IC chip implementation substrate has a light-signal transmitting optical path disposed therein which passes through the IC chip implementation substrate, that the multilayer printed wiring board includes a substrate and a conductor circuit, and has a light-signal transmitting optical path formed therein which passes through at least the substrate, and that each of the light-signal transmitting optical paths has a glossy metal layer formed on part of or all over a wall surface of the light-signal

transmitting optical path.

[0227]

With regard to the optical communication device of the third aspect of the present invention, since the glossy metal layer formed on part of or all over the wall surface of the light-signal transmitting optical path can favorably reflect the light signal transmitted in the light-signal transmitting optical path, the light signal is less prone to be attenuated or absorbed when impinging on the wall surface of the light-signal transmitting optical path. Accordingly, with the optical communication device of the third aspect of the present invention, since the loss of the light signal transmitted in the light-signal transmitting optical path is less prone to occur, the optical communication device is excellent in the light-signal transmission reliability, making it possible to realize reliable optical communication.

[0228]

With regard to the optical communication device of the third aspect of the present invention, a light-signal transmitting optical path passing through the IC chip implementation substrate is disposed in the IC chip implementation substrate constituting the optical communication device, and a light-signal transmitting optical path passing through at least the substrate is disposed in the multilayer printed wiring board

constituting the optical communication device. The optical communication device of the third aspect of the present invention in which such light-signal transmitting optical paths are disposed can transmit light signals via the light-signal transmitting optical path disposed in the IC chip implementation substrate, and the light-signal transmitting optical path disposed in the multilayer printed wiring board.

[0229]

In the optical communication device of the third aspect of the present invention, the light-signal transmitting optical path has a glossy metal layer formed on part of or all over the wall surface thereof. If the glossy metal layer is formed on part of or all over the wall surface of the light-signal transmitting optical path in this way, when the light signal transmitted in the light-signal transmitting optical path impinges on the wall surface of the light-signal transmitting optical path, the light signal is favorably reflected by the glossy metal layer, so the loss of the light signal is less prone to occur, and it is possible to improve the light-signal transmission reliability. Although the glossy metal layer is formed on part of the wall surface of the light-signal transmitting optical path, or is formed all over the wall surface thereof, if the glossy metal layer is formed on part of the wall surface of the light-signal transmitting

optical path, it is preferable that the glossy metal layer be formed on the wall surface of the part of the light-signal transmitting optical path, which part passes through the substrate and the interlayer resin insulation layer. This is because, normally, the substrate and the interlayer resin insulation layer have high adhesion to metal, and a solder resist layer has low adhesion to metal.

[0230]

In addition, it is preferable that the light-signal transmitting optical path include a cavity. If the light-signal transmitting optical path includes a cavity, the formation thereof is easy, and the transmission loss is less prone to occur in transmitting the light signal via the light-signal transmitting optical path. Whether or not to make the constitution of the light-signal transmitting optical path include a cavity may be appropriately decided in consideration of the thickness of the IC chip implementation substrate or the multilayer printed wiring board, or the like.

[0231]

It is also preferable that the light-signal transmitting optical path include a resin composite. If the light-signal transmitting optical path includes the resin composite, the reduction in strength of the IC chip implementation substrate or the multilayer printed wiring board can be prevented. In addition, if the light-signal

transmitting optical path is comprised of the resin composite, it is possible to prevent dust, contaminants or the like from entering into the light-signal transmitting optical path, so it is possible to prevent the transmission of light signals from being impeded due to the existence of the dust, contaminants or the like.

[0232]

It is also preferable that the light-signal transmitting optical path include a resin composite and a cavity. If the light-signal transmitting optical path includes the resin composite and the cavity, it is possible to prevent the reduction in strength of the IC chip implementation substrate or the multilayer printed wiring board. If the light-signal transmitting optical path includes the resin composite and the cavity, it is preferable that the light-signal transmitting optical path formed in the part passing through the substrate and the interlayer resin insulation layer be comprised of the resin composite, and the light-signal transmitting optical path formed in the solder resist layer be comprised of the cavity. This is because, normally, the substrate and the interlayer insulation layer have high adhesion to resin, and the solder resist layer has low adhesion to resin.

[0233]

The IC chip implementation substrate constituting the optical communication device of the third aspect of

the present invention is not particularly limited, as long as the IC chip implementation substrate has the light-signal transmitting optical path formed therein which passes through the IC chip implementation substrate. For example, one similar to the IC chip implementation substrate constituting the optical communication device of the first aspect of the present invention can be named. By using such an IC chip implementation substrate, it is possible to obtain the above-described various effects.

[0234]

The multilayer printed wiring board constituting the optical communication device of the third aspect of the present invention is not particularly limited, as long as the multilayer printed wiring board includes the substrate and the conductor circuit, and has the light-signal transmitting optical path formed therein which passes through at least the substrate. For example, one similar to the multilayer printed wiring board constituting the optical communication device of the second aspect of the present invention can be named. By using such a multilayer printed wiring board, it is possible to obtain the above-described various effects.

[0235]

Specifically, since the IC chip implementation substrate and the multilayer printed wiring board have the light-signal transmitting optical paths formed therein,

the flexibility of the positions at which the optical elements are implemented, and the positions at which the optical waveguides are formed is increased when the optical elements are implemented on the IC chip implementation substrate, or when the optical waveguides are formed in the multilayer printed wiring board. Accordingly, it is possible to make the density of the IC chip implementation substrate and the multilayer printed wiring board higher. This is because the free space available in designing the IC chip implementation substrate and the multilayer printed wiring board becomes large.

[0236]

In addition, it is possible to perform alignment of the implementation positions of the optical elements and the formation positions of the optical waveguides by an optical process or a mechanical process, using, as reference points, the light-signal transmitting optical paths formed in each of the IC chip implementation substrate and the multilayer printed wiring board, accordingly, it is possible to implement the optical elements and the optical waveguides accurately at desired positions. In addition, with regard to the light-signal transmitting optical path constructed as described above, a harmful influence caused by heat or the like is less prone to occur during a heat treatment process or a reliability test.

[0237]

Description will be given below of the optical communication device of the third aspect of the present invention with reference to the drawings. Fig. 4 is a cross-sectional view schematically showing an embodiment of the optical communication device of the third aspect of the present invention. In Fig. 4, there is shown the optical communication device with an IC chip implemented thereon.

[0238]

As shown in Fig. 4, the optical communication device 450 of the third aspect of the present invention is comprised of: the IC chip implementation substrate 420 on which an IC chip 440 is implemented; and the multilayer printed wiring board 400. The IC chip implementation substrate 420 and the multilayer printed wiring board 400 are electrically connected via solder connections 441.

[0239]

With regard to the optical communication device 450, the IC chip implementation substrate 420 has light-signal transmitting optical paths 451 formed therein which pass through the IC chip implementation substrate 420. The light-signal transmitting optical path 451 has a metal layer 451b formed on part of the wall surface thereof, and an optical-path resin layer 451a formed in part of the inside thereof. The construction of the IC chip implementation substrate 420 is the same as that of the IC chip

implementation substrate 220 shown in Fig. 1.

[0240]

The multilayer printed wiring board 400 has light-signal transmitting optical paths 461 formed therein which pass through a substrate 401, interlayer insulation layers 402, and solder resist layers 414, so that the multilayer printed wiring board is constructed to be able to transmit light signals between each of the light receiving element 438 and the light emitting element 439 and the optical waveguide 419 via the light-signal transmitting optical path 461. The light-signal transmitting optical path 461 has a metal layer 461b formed on part of the wall surface thereof, and has an optical-path resin layer 461a formed in part of the inside thereof. The construction of the multilayer printed wiring board 400 is the same as that of the multilayer printed wiring board 300 shown in Fig. 2. In the optical communication device 450, transmission of light signals can be performed by the light receiving element 438, the light emitting element 439, and the optical waveguides 419 via the light-signal transmitting optical paths 451 formed in and passing through the IC chip implementation substrate 420, and the light-signal transmitting optical paths 461 formed in the multilayer printed wiring board 400 which paths pass through the substrate 401, the interlayer insulation layers 402, and the solder resist layers 414. Embodiments of the

optical communication device of the third aspect of the present invention are not limited to the embodiment shown in Fig. 4. Embodiments as shown in Figs. 5 and 6 can be adopted, for example.

[0241]

In the IC chip implementation substrate 550 shown in Fig. 5, a light receiving element 538 is implemented on the IC chip implementation substrate 520 on the side thereof facing the multilayer printed wiring board 500, and a light emitting element 539 is implemented on the opposite side from the side facing the multilayer printed wiring board 500. In addition, a light-signal transmitting optical path 551 passing through the IC chip implementation substrate 520 is formed so that the light emitting element 539 can transmit light signals between itself and an optical waveguide formed in the multilayer printed wiring board 500. The light-signal transmitting optical path 551 has a metal layer 551b formed on part of the wall surface thereof, and part of the inside thereof is filled with an optical-path resin layer 551a.

[0242]

In the multilayer printed wiring board 500, optical waveguides are formed. The optical waveguide 518a for transmitting light signals between itself and the light receiving element 538 is formed on an interlayer insulation layer 502 which is the outermost layer on the side near

the IC chip implementation substrate 520 with respect to the substrate 501. The optical waveguide 518b for transmitting light signals between itself and the light emitting element 539 is formed on an interlayer insulation layer 502 which is the outermost layer on the opposite side from the IC chip implementation substrate 520 with respect to the substrate 501. In addition, in the multilayer printed wiring board 500, formed is a light-signal transmitting optical path 561 for transmitting light signals between the light emitting element 539 and the optical waveguide 518b. The light-signal transmitting optical path 561 is formed so as to pass through the substrate 501, the interlayer insulation layers 502, and solder resist layers 514. The light-signal transmitting optical path 561 has a metal layer 561b formed on part of the wall surface thereof, and part of the inside thereof is filled with an optical-path resin layer 561a.

[0243]

In the optical communication device 550, transmission of light signals can be performed by the light emitting element 539, and the optical waveguide 519b via the light-signal transmitting optical path 551 formed in and passing through the IC chip implementation substrate 520, and the light-signal transmitting optical path 561 formed in the multilayer printed wiring board 500 which path passes through the substrate 501, the interlayer

insulation layers 502, and the solder resist layers 514. In addition, transmission of light signals can be performed by the light receiving element 538, and the optical waveguide 519a via an optical-path opening 511a formed in the solder resist layer in the multilayer printed wiring board 500.

[0244]

In the IC chip implementation substrate 650 shown in Fig. 6, a light receiving element 638 is implemented on the IC chip implementation substrate 620 on the opposite side thereof from the side facing the multilayer printed wiring board 600, and a light emitting element 639 is implemented on the side facing the multilayer printed wiring board 600. In addition, a light-signal transmitting optical path 651 passing through the IC chip implementation substrate 620 is formed so that the light receiving element 638 can transmit light signals between itself and an optical waveguide 618a formed in the multilayer printed wiring board 600. The light-signal transmitting optical path 651 has a metal layer 651b formed on part of the wall surface thereof, and part of the inside thereof is filled with an optical-path resin layer 651a.

[0245]

In the multilayer printed wiring board 600, optical waveguides 619 are formed. The optical waveguide 618a for transmitting light signals between itself and the light

receiving element 638 is formed on an interlayer insulation layer which is the outermost layer on the side near the IC chip implementation substrate 620 with respect to the substrate 601. The optical waveguide 618b for transmitting light signals between itself and the light emitting element 639 is formed on an interlayer insulation layer which is the outermost layer on the opposite side from the IC chip implementation substrate 620 with respect to the substrate 601. In addition, in the multilayer printed wiring board 600, formed is a light-signal transmitting optical path 651 for transmitting light signals between the light emitting element 639 and the optical waveguide 618b. The light-signal transmitting optical path 661 is formed so as to pass through the substrate 601, the interlayer insulation layers 602, and solder resist layers 614. The light-signal transmitting optical path 661 has a metal layer 661b formed on part of the wall surface thereof, and part of the inside thereof is filled with an optical-path resin layer 661a.

[0246]

In the optical communication device 650, transmission of light signals can be performed by the light emitting element 639, and the optical waveguide 619b via the light-signal transmitting optical path 661 formed in the multilayer printed wiring board 600 which path passes through the substrate 601, the interlayer insulation layers

602, and the solder resist layers 614. In addition, transmission of light signals can be performed by the light receiving element 638, and the optical waveguide 619a via the light-signal transmitting optical path 651 formed in and passing through the IC chip implementation substrate 620.

[0247]

As mentioned above, embodiments of optical communication device of the third aspect of the present invention are not limited to the embodiments shown in Figs. 4 to 6. The embodiments have only to be combinations given by appropriately choosing the implementation positions of the light receiving elements and the light emitting elements, the formation positions of the optical waveguides, and whether or not the light-signal transmitting optical paths are formed.

[0248]

Although the positions at which the optical waveguides are formed in the multilayer printed wiring boards shown in Figs. 4 to 6 are on the interlayer insulation layer which is the outermost layer, the formation positions of the optical waveguides are not limited to the positions in the multilayer printed wiring board constituting the optical communication device of the third aspect of the present invention, and may be between the interlayer insulation layers, or on the substrate.

[0249]

Since the materials for the light-signal transmitting optical paths, the optical elements, the optical waveguides and others, and the like in the optical communication device of the third aspect of the present invention are similar to those of the optical communication device of the first aspect of the present invention, description thereof is omitted. The optical communication device of the third aspect of the present invention having such a construction can be manufactured by the method of manufacturing an optical communication device of the sixth aspect of the present invention to be described later, for example.

[0250]

Description will now be given of the method of manufacturing an optical communication device of the sixth aspect of the present invention. The method of manufacturing an optical communication device of the sixth aspect of the present invention is characterized in that an IC chip implementation substrate is produced by a process including: (a) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (b) a penetration-hole forming step of forming a penetration hole in the multilayer

interconnection board; (c) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (d) an optical-element implementation step of implementing an optical element at such a position that a light signal can be transmitted via the penetration hole, and that, after a multilayer printed wiring board is separately produced by a process including: (A) a multilayer-interconnection-board producing step of forming a conductor circuit and an interlayer resin insulation layer on each side of a substrate in a stacked manner to thereby obtain a multilayer interconnection board; (B) a penetration-hole forming step of forming a penetration hole in the multilayer interconnection board; (C) a metal-layer forming step of forming a glossy metal layer on a wall surface of the penetration hole; and (D) an optical-waveguide forming step of forming an optical waveguide at such a position that a light signal can be transmitted via the penetration hole, both of the IC chip implementation substrate and the multilayer printed wiring board are placed and fixed to each other in such positions that a light signal can be transmitted between the optical element of the IC chip implementation substrate and the optical waveguide of the multilayer printed wiring board.

[0251]

With regard to each of the IC chip implementation substrate and the multilayer printed wiring board

constituting the optical communication device manufactured by the method of manufacturing an optical communication device of the sixth aspect of the present invention, the glossy metal layer is formed on part of or all over them, and the metal layer can favorably reflect the light signal transmitted in the light-signal transmitting optical path. Accordingly, since the light signal is less prone to be attenuated or absorbed when impinging on the wall surface of the light-signal transmitting optical path, and the loss of the light signal transmitted in the light-signal transmitting optical path is therefore less prone to occur, the optical communication device is excellent in the light-signal transmission reliability, making it possible to realize reliable optical communication. Accordingly, with the method of manufacturing an optical communication device of the sixth aspect of the present invention, it is possible to manufacture an optical communication device in which the connection loss between the implemented optical components is low, and which is excellent in the connection reliability. The optical communication device can also be manufactured by producing the IC chip implementation substrate and the multilayer printed wiring board separately, and then connecting both of them via solder or the like, as in the case of the method of manufacturing an optical communication device of the fourth aspect of the present

invention. Accordingly, in relation to this embodiment, description will first be given of respective processes of producing the IC chip implementation substrate and the multilayer printed wiring board, and description will then be given of a method of connecting both of them.

[0252]

As the process of producing the IC chip implementation substrate, a process similar to that of producing the IC chip implementation substrate in the method of manufacturing an optical communication device of the fourth aspect of the present invention, can be used, for example. When the IC chip implementation substrate is formed, the formation of a solder resist layer may be performed as appropriate.

[0253]

As the process of producing the multilayer printed wiring board, a process similar to that of producing the multilayer printed wiring board in the method of manufacturing an optical communication device of the fifth aspect of the present invention, can be used, for example. When the multilayer printed wiring board is formed, the formation of a solder resist layer may be performed as appropriate.

[0254]

Subsequently, the IC chip implementation substrate and the multilayer printed wiring board produced by the

above-described processes are connected to thereby manufacture the optical communication device. Specifically, this may be carried out by a method similar to that employed for manufacturing an optical communication device of the fourth aspect of the present invention.

[0255]

The IC chip implemented in the methods of manufacturing an optical communication device of the fourth to sixth aspects of the present invention may be implemented by wire bonding, or may be implemented by flip-chip bonding. However, it is preferable that the IC chip be implemented by flip-chip bonding.

[0256]

(Example)

The present invention will be explained in further detail below.

(Example 1)

A. Preparation of IC chip implementation substrate

A-1. Preparation of Resin film for Interlayer resin insulation layer

30 wt parts of bisphenol A-type epoxy resin (epoxy equivalent: 469, Epicoat 1001, made by Yuka Shell Epoxy Co., Ltd.), 40 wt parts of cresol-novolac type epoxy resin (epoxy equivalent: 215, Epiclon N-673, made by Dainippon Ink and Chemicals, Inc.), and 30 wt parts of triazine structure containing phenol-novolac resin (phenol

hydroxyl equivalent: 120, Phenolite KA-7052 made by Dainippon Ink and Chemicals, Inc.) were dissolved while being heated in 20 wt parts of ethyl diglycol acetate and 20 wt parts of solvent naphtha under stirring condition, followed by the addition of 15 wt parts of epoxy-terminated polybutadiene rubber (Denalex R-45EPT, made by Nagase Chemicals Ltd.) and 1.5 wt parts of a pulverized product of 2-phenyl-4,5-bis(hydroxymethyl)imidazole, 2 wt parts of a finely pulverized silica, and 0.5 wt parts of a silicone-based defoaming agent to thereby prepare an epoxy resin composite. After the obtained epoxy resin composite was applied to a 38 μm-thick PET film by a roll coater so that the thickness is 50 μm after drying, the resulting film was dried at 80 to 120°C for 10 minutes to thereby produce a resin film for an interlayer resin insulation layer.

[0257]

A-2. Preparation of Resin Composite for filling Penetration Hole

100 wt parts of bisphenol F-type epoxy monomer (molecular weight: 310, YL 983 U, made by Yuka Shell Epoxy Co., Ltd.), 170 wt parts of SiO_2 spherical particles coated with a silane coupling agent and having an average grain size of 1.6μm a diameter of the largest particle of which particles is 15 μm or less (CRS 1101-CE, made by Adtec Co., Ltd.), and 1.5 wt parts of a leveling agent (Perenol S4,

made by San Nopco Ltd.) were put into a container, and were stirred and mixed to thereby prepare a resin filler with a viscosity of 45 to 49 Pa·s at 23±1°C. As a curing agent, 6.5 wt parts of an imidazole curing agent (2E4MZ-CN, made by Shikoku Chemicals Corp.) was used.

[0258]

A-3. Production of IC chip implementation substrate

(1) A copper-clad laminate having a 18 μm-thick copper foil 28 laminated to each side of the insulating substrate 21 made of a 0.8 mm-thick glass-epoxy resin or BT (bismaleimide-triazine) resin was used as a starting material (see Fig. 7(a)). First, the copper-clad laminate was drilled to bore holes, an electroless plating process was performed, and pattern etching was performed to thereby form conductor circuits 24 and through holes 29 on both sides of the substrate 21 (see Fig. 7(b)).

[0259]

(2) After the substrate in which the through holes 29 and the conductor circuits 24 were formed was washed with water and dried, the substrate was subjected to a blackening process using an aqueous solution containing NaOH (10 g/l), $NaClO_2$ (40 g/l), Na_3PO_4 (6 g/l) as a blackening bath (an oxidizing bath) and a reducing process using an aqueous solution containing NaOH (10 g/l) and $NaBH_4$ (6 g/l) as a reducing bath to thereby form roughened surfaces (not shown) in the surfaces of the conductor circuits 24

including the through holes 29.

[0260]

(3) After the resin filler described in the process A-2 was prepared, the layer of the resin filler 30' was formed in the through holes 29, on the conductor-circuit non-formed part on one side of the substrate 21, and on the peripheral portions of the conductor circuits 24 within 24 hours of the preparation by the following method. That is, first, the resin filler was pushed in the through holes with the use of a squeegee, and then dried under the conditions of 100°C for 20 minutes. Subsequently, a mask in which the areas corresponding to the conductor-circuit non-formed part were opened was put on the substrate, and the resin filler was filled into the conductor-circuit non-formed part, which was concave, with the use of a squeegee. Thereafter, the substrate was dried under the conditions of 100°C for 20 minutes to thereby form the layer of the resin filler 30' (see Fig. 7(c)).

[0261]

(4) One surface of the substrate for which the above-described process (3) was finished was ground by a belt sander grinder using #600 belt grinding-paper (made by Sankyo Rikagaku Co., Ltd.) so as not to leave the resin filler 30' on the surfaces of the conductor circuits 24 and the land surfaces of the through holes 29. Subsequently, buffing was performed to remove the scratches due to the

above-mentioned belt sander grinding. A series of such grinding steps were performed for the other surface of the substrate in the same manner. Subsequently, a heating process at 100°C for an hour, 120°C for 3 hours, 150°C for an hour, and 180°C for 7 hours was performed to thereby form a resin filler layer 30.

[0262]

In this way, the surface portion of the resin filler 30 formed in the through holes 29 and the conductor circuit non-formed part, and the surfaces of the conductor circuits 24 were planarized to thereby obtain an insulating substrate in which the resin filler 30 and the side surfaces of the conductor circuits 24 were firmly and closely adhered to each other through the roughened surfaces, and, in addition, the inner wall surfaces of the through holes 29 and the resin filler 30 were firmly and closely adhered to each other through the roughened surfaces (see Fig. 7(d)). By this step, the surface of the resin filler layer 30 comes to be flush with the surfaces of the conductor circuits 24.

[0263]

(5) After the substrate was washed with water and degreased with acid, soft etching was performed. Subsequently, an etchant was sprayed on both sides of the substrate to etch the surfaces of the conductor circuits 24 and the land surfaces of the through holes 29, to thereby

form the roughened surfaces (not shown) in the all surfaces of the conductor circuits 24. As the etchant, an etchant (Mec Etch bond, made by Mec Co., Ltd.) containing 10 wt parts of an imidazole copper(II) complex, 7 wt parts of glycolic acid, and 5 wt parts of potassium chloride was used.

[0264]

(6) Subsequently, a resin film for the interlayer resin insulation layer slightly larger in size than the substrate produced by the above-described process A-1 was put on the substrate, subjected to temporary pressure lamination under the conditions: a pressure of 0.4 MPa, a temperature of 80°C, and a pressure-lamination time of 10 s, and then cut. Thereafter, the resin film was laminated to the substrate by the following method using a vacuum laminator to thereby form interlayer resin insulation layers 22 (see Fig. 7(e)). That is, the resin film for the interlayer resin insulation layer was subjected to complete pressure lamination to the substrate under the conditions: a degree of vacuum of 65 Pa, a pressure of 0.4 MPa, a temperature of 80°C, and a pressure-lamination time of 60 s. Thereafter, the resin film was thermally cured at 170°C for 30 minutes.

[0265]

(7) Subsequently, via-hole openings 26 with a diameter of 80μm were formed in the interlayer resin insulation layers 22 via a CO_2 gas laser with a wavelength of 10.4μm

through a 1.2 mm-thick mask having penetration holes under conditions: a beam diameter of 4.0 mm, a top hat mode, a pulse width of 8.0 μs, a diameter of the penetration holes of the mask of 1.0 mm, and one shot (see Fig. 8(a)).

[0266]

(8) The substrate in which the via-hole openings 26 were formed was immersed in a solution containing 60 g/l of permanganic acid at 80°C for 10 minutes to dissolve and remove the epoxy resin particles existing in the surfaces of the interlayer resin insulation layers 22, to thereby form the roughened surfaces (not shown) in the interlayer resin insulation layers 22 including the inner wall surfaces of the via-hole openings 26.

[0267]

(9) Subsequently, the substrate subjected to the above-described process was immersed in a neutralizer (made by Shipley Co.), and washed with water. Further, a palladium catalyst was provided to the surface of the substrate subjected to the surface roughening process (the roughening depth: 3 μm), so that catalyst core was adhered to the surfaces of the interlayer resin insulation layers 22 (including the inner wall surfaces of the via-hole openings 26) (not shown). Specifically, the substrate was immersed in a catalyst solution containing palladium chloride ($PdCl_2$) and stannous chloride ($SnCl_2$), and palladium metal was precipitated, to thereby provide the

catalyst.

[0268]

(10) Subsequently, the substrate was immersed in an electroless copper plating aqueous solution having the following composition to thereby form electroless copper plating films 32 with a thickness of 0.6 to 3.0 μm on the surfaces of the interlayer resin insulation layers 22 (including the inner wall surfaces of the via-hole openings 26) (see Fig. 8(b)).

[0269]

[Electroless plating aqueous solution]

$NiSO_4$	0.003 mol/l
Tartaric acid	0.200 mol/l
Copper sulfate	0.030 mol/l
HCHO	0.050 mol/l
NaOH	0.100 mol/l
α,α'-bipyridyl	100 mg/l
Polyethylene glycol (PEG)	0.10 g/l

[Electroless Plating Condition]

30°C Liquid Temperature for 40 Minutes

[0270]

(11) Subsequently, a commercially available photosensitive dry film was laminated to the substrate on which the electroless copper plating films 32 were formed; a mask was put thereon; and exposure at a dose of 100 mJ/cm^2 and development with an aqueous 0.8% sodium carbonate

solution were performed, to thereby provide plating resists 23 with a thickness of 20 μm (see Fig. 8(c)).

[0271]

(12) Subsequently, the substrate was washed with water at 50°C to degrease, washed with water at 25°C, and further washed with sulfuric acid. Thereafter, the substrate was subjected to electroplating under the following conditions to thereby form electroplating copper films 33 with a thickness of 20μm on the plating-resist-23 non-formed part (see Fig. 8(d)).

[0272]

[Electroplating solution]

Sulfuric acid	2.24 mol/l
Copper sulfate	0.26 mol/l
Additive	19.5 ml/l

(Cupracid GL, made by Atotech Japan Co., Ltd.)

[Electroplating conditions]

Current density	1 A/dm^2
Time	65 minutes
Temperature	22±2°C

[0273]

(13) After detaching and removing the plating resists 23 with 5% NaOH, the electroless plating films under the plating resists 23 were etched, dissolved and removed with a solution mixture of sulfuric acid and hydrogen peroxide, to thereby form conductor circuits 25 (including via-holes

27) each made of the electroless copper plating film 32 and the electroplating copper film 33 and having a thickness of 18 μm (see Fig. 9(a)).

[0274]

(14) Roughened surfaces (not shown) were formed in the surfaces of the conductor circuits 25, using an etchant similar to that used in the step (5). Subsequently, interlayer resin insulation layers 22 having via-hole openings 26 and having roughened surface (not shown) formed in the surface thereof were formed in a stacked manner by a process similar to that employed in the steps (6) to (8) (see Fig. 9(b)). Thereafter, optical-path penetration holes 46 passing through the substrate 21 and the interlayer resin insulation layers 22 were formed via a drill with a diameter of 300 μm, and a desmear process was performed to the wall surfaces of the optical-path penetration holes 46 (see Fig. 9(c)). It should be noted that the diameter of the drill used when the optical-path penetration holes are formed is preferably from 200 to 400 μm, and, with regard to this example, a drill with a diameter of 300 μm was used.

[0275]

(15) Subsequently, by a method similar to that employed in the step (9), a catalyst was provided to the surfaces of the wall surfaces of the optical-path penetration holes 46 and the surfaces of the interlayer resin insulation layers 22. Then, the substrate was immersed in an

electroless copper plating aqueous solution similar to the electroless plating solution used in the step (10), to thereby form thin film conductor layers (electroless copper plating films) 32 on the surfaces of the interlayer resin insulation layers 22 (including the inner wall surfaces of the via-hole openings 26), and the wall surfaces of the optical-path penetration holes 46 (see Fig. 10(a)).

[0276]

(16) Subsequently, by a method similar to that employed in the step (11), plating resists 38 were provided all over the interlayer resin insulation layers 22 (except the portions of the thin film conductor layer 32 formed on the wall surfaces of the optical-path penetration holes 46). The substrate was then immersed in an electroless gold plating solution containing potassium gold cyanide (7.6×10^{-3} mol/l), ammonium chloride (1.9×10^{-1} mol/l), sodium citrate (1.2×10^{-1} mol/l), and sodium hypophosphite (1.7×10^{-1} mol/l) for 7.5 minutes under the condition of 80°C to thereby form a metal layer (a gold plating layer) 45 on the wall surfaces of the optical-path penetration holes 46. Thereafter, the plating resists 38 was detached and removed with 5% NaOH.

[0277]

(17) Subsequently, by a method similar to that employed in the step (11), plating resists 23 were provided to the part including the end face portions of the optical-path

penetration holes having the metal layer 45 formed therein. In addition, by a method similar to that employed in the step (12), electroplating copper films 33 with a thickness of 20μm were formed on the plating-resist-23 non-formed part (see Fig. 10(b)).

[0278]

(18) Subsequently, by a method similar to that employed in the step (13), detaching of the plating resists 23 and removing of the thin film conductor layer under the plating resists 23 were performed, to thereby form conductor circuits 25 (including via holes 27) (see Fig. 10(c)).

[0279]

(19) Subsequently, a resin composite containing epoxy resin was filled into the optical-path penetration holes 46 having the metal layer 45 formed therein, using a squeegee, and was then dried. Thereafter, the surface thereof was planarized by buffing. Further, a curing process was performed to thereby form an optical-path resin layer 42 (see Fig. 11(a)). In addition, by a method similar to that employed in the step (2), an oxidizing-reducing process was performed to thereby turn the surfaces of the conductor circuits 25 into roughened surfaces (not shown).

[0280]

(20) Subsequently, 46.67 wt parts of an oligomer provided with a photosensitivity (molecular weight: 4000) obtained by acrylating 50% of an epoxy group of cresol-novolac type

epoxy resin (made by Nippon Kayaku Co., Ltd.), dissolved in diethylene glycol dimethyl ether (DMDG) to be 60wt%; 15.0 wt parts of bisphenol A-type epoxy resin (trade name: Epicoat 1001 made by Yuka Shell Epoxy Co., Ltd.) dissolved in methyl ethyl ketone to be 80wt%; 1.6 wt parts of imidazole curing agent (tradename: 2E4MZ-CN, made by Shikoku Chemicals Corp.); 4.5 wt parts of a bifunctional acrylic monomer, which was a photosensitive monomer (trade name: R604, made by Nippon Kayaku Co., Ltd.); 1.5 wt parts of a similarly polyvalent acrylic monomer (trade name: DPE6A, made by Kyoei Chemical Co., Ltd.); and 0.71 wt parts of a dispersion-type defoaming agent (S-65, made by San Nopco Ltd.) were put into a container, and were stirred and mixed to thereby prepare a mixed composite. Then, 2.0 wt parts of benzophenone (made by Kanto Chemical Co., Inc.) as a photoinitiator, and 0.2 wt parts of Michler's ketone (made by Kanto Chemical Co., Inc.) as a photosensitizer were added to the mixed composite to thereby obtain a solder resist composite the viscosity of which was tailored to be 2.0 Pa•s at 25°C. The viscosity measurement was performed using a Brookfield viscometer (DVL-B type, made by Tokyo Keiki Co., Ltd.), using a rotor No. 4 in the case of 60 min^{-1} (rpm), or a rotor No. 3 in the case of 6 min^{-1} (rpm).

[0281]

(21) Subsequently, the solder resist composite was applied, at a thickness of 30 μm, to each side of the

substrate on which the interlayer resin insulation layers 22 and the conductor circuits 25 (including via-holes 27) had been formed, and then dried under conditions of 70°C for 20 minutes, and 70°C for 30 minutes, to thereby form solder resist composite layers 34' (see Fig. 11(b)).

[0282]

(22) A photomask with a thickness of 5 mm on which a pattern of the optical-path openings and the solder-bump forming openings (IC-chip implementing openings and optical-element implementing openings) was drawn was placed closely to the solder resist composite layer 34' on the side on which the IC chip was to be implemented, and the exposure to UV light at 1000 mJ/cm^2 was performed. Then, a development process was performed with the DMTG solution to thereby form openings. Further, a heat process was performed at 80°C for an hour, 100°C for an hour, 120°C for an hour, and 150°C for 3 hours to cure the solder resist composite layers, to thereby form solder resist layers 34 with a thickness of 20 μm having optical-path openings 31 and solder-bump forming openings 35. On the other hand, in the other solder resist composite layer, solder-bump forming openings 35 for connection with the multilayer printed wiring board were formed by the following process. A photomask on which a pattern of the solder-bump forming openings (openings for connection with the multilayer printed wiring board) was drawn was placed closely to the

solder resist composite layer. Then, an exposure and development process was performed under conditions similar to the above exposure and development conditions (see Fig. 12(a)).

[0283]

(23) Subsequently, a resin composite similar to that containing epoxy resin filled in the step (19) was filled into the optical-path openings formed in the step (22), using a squeegee, and was then dried. Thereafter, the surface thereof was planarized by buffing. Further, a curing process was performed to thereby form an optical-path resin layer 42. With regard to the optical-path resin layer formed in this step, and that formed in the step (19), the transmittance was 85%, and the refractive index was 1.60.

[0284]

(24) Subsequently, the substrate on which the solder resist layers 34 were formed was immersed in an electroless nickel plating solution having pH 4.5 and containing nickel chloride (2.3×10^{-1} mol/l), sodium hypophosphite (2.8×10^{-1} mol/l), and sodium citrate (1.6×10^{-1} mol/l) for 20 minutes to thereby form a 5 μm-thick nickel plating layer in the solder-bump forming openings 35 and the optical-element implementing openings 31. Further, the obtained substrate was immersed in an electroless gold plating solution containing potassium gold cyanide (7.6

x 10^{-3} mol/l), ammonium chloride (1.9 x 10^{-1} mol/l), sodium citrate (1.2 x 10^{-1} mol/l), and sodium hypophosphite (1.7 x 10^{-1} mol/l) for 7.5 minutes under the condition of 80°C to thereby form a 0.03 μm-thick gold plating layer on each nickel plating layer, and obtain solder pads 36.

[0285]

(25) Subsequently, solder paste was applied to the solder-bump forming openings 35 formed in the solder resist layers 34 by printing, and, in addition, a light receiving element 38 and a light emitting element 39 were attached to the solder paste applied by printing in the respective optical-element implementing openings while alignment of respective light receiving and emitting parts 38a and 39a was performed. Then, reflow was performed at 200°C to thereby implement the light receiving element 38 and the light emitting element 39 via solder. In addition, solder bumps 37 were formed in the IC-chip implementing openings and the multilayer-printed-wiring-board implementing openings, to thereby obtain an IC chip implementation substrate (see Fig. 12(b)). As the light receiving element 38, an optical element made of InGaAs was used. As the light emitting element 39, an optical element made of InGaAsP was used.

[0286]

B. Preparation of Multilayer printed wiring board

B-1. Preparation of Resin film for Interlayer resin

insulation layer

By a method similar to that employed in the process A-1, resin films for the interlayer resin insulation layer were prepared.

B-2. Preparation of Resin Composite for filling Penetration Hole

By a method similar to that employed in the process A-2, a resin composite for filling the penetration holes was prepared.

[0287]

B-3. Production of Multilayer printed wiring board

(1) A copper-clad laminate having a 18 μm-thick copper foil 4' laminated to each side of an insulating substrate 1 made of a 0.6 mm-thick glass-epoxy resin or BT (bismaleimide-triazine) resin was used as a starting material (see Fig. 13(a)). First, the copper-clad laminate was drilled to bore holes, an electroless plating process was performed, and pattern etching was performed to thereby form conductor circuits 4 and through holes 9 on both sides of the substrate 1 (see Fig. 13(b)).

[0288]

(2) After the substrate in which the through holes 9 and the conductor circuits 4 were formed was washed with water and dried. Thereafter, an etchant (made by Mec Co., Ltd., Mec Etch Bond) was sprayed on the substrate to thereby form roughened surfaces (not shown) in the surfaces of the

conductor circuits 4 including the through holes 9.

[0289]

(3) After the resin filler described in the process B-2 was prepared, a layer of a resin filler 10' was formed in the through holes 9, on the conductor-circuit non-formed part on one side of the substrate 1, and on the peripheral portions of the conductor circuits 4 within 24 hours of the preparation by the following method. That is, first, the resin filler was pushed in the through holes with the use of a squeegee, and then dried under the conditions of 100°C for 20 minutes. Subsequently, a mask in which the areas corresponding to the conductor-circuit non-formed part were opened was put on the substrate, and the resin filler was filled into the conductor-circuit non-formed part, which was concave, with the use of a squeegee. Thereafter, the substrate was dried under the conditions of 100°C for 20 minutes to thereby form the layer of the resin filler 10' (see Fig. 13(c)).

[0290]

(4) One surface of the substrate for which the above-described process (3) was finished was ground by a belt sander grinder using #600 belt grinding-paper (made by Sankyo Rikagaku Co., Ltd.) so as not to leave the resin filler 10' on the surfaces of the conductor circuits 4 and the land surfaces of the through holes 9. Subsequently, buffing was performed to remove the scratches due to the

above-mentioned belt sander grinding. A series of such grinding steps were performed for the other surface of the substrate in the same manner. Subsequently, a heating process at 100°C for an hour, 120°C for 3 hours, 150°C for an hour, and 180°C for 7 hours was performed to thereby form a resin filler layer 10.

[0291]

In this way, the surface portion of the resin filler 10 formed in the through holes 9 and the conductor circuit non-formed part, and the surfaces of the conductor circuits 4 were planarized to thereby obtain an insulating substrate in which the resin filler 10 and the side surfaces of the conductor circuits 4 were firmly and closely adhered to each other through the roughened surfaces, and, in addition, the inner wall surfaces of the through holes 9 and the resin filler 10 were firmly and closely adhered to each other through the roughened surfaces (see Fig. 13(d)). By this step, the surface of the resin filler layer 10 comes to be flush with the surfaces of the conductor circuits 4.

[0292]

(5) After the substrate was washed with water and degreased with acid, soft etching was performed. Subsequently, an etchant was sprayed on both sides of the substrate to etch the surfaces of the conductor circuits 4 and the land surfaces of the through holes 9, to thereby form the roughened surfaces (not shown) in the all surfaces

of the conductor circuits 4. As the etchant, Mec Etch bond, made by Mec Co., Ltd. was used.

[0293]

(6) Subsequently, a resin film for the interlayer resin insulation layer slightly larger in size than the substrate produced by the above-described process B-1 was put on the substrate, is subjected to temporary pressure lamination under the conditions: a pressure of 0.4 MPa, a temperature of 80°C, and a pressure-lamination time of 10 s, and then cut. Thereafter, the resin film was laminated to the substrate by the following method using a vacuum laminator to thereby form interlayer resin insulation layers 2 (see Fig. 13(e)). That is, the resin film for the interlayer resin insulation layer was subjected to complete pressure lamination to the substrate under the conditions: a degree of vacuum of 65 Pa, a pressure of 0.4 MPa, a temperature of 80°C, and a pressure-lamination time of 60 s. Thereafter, the resin film was thermally cured at 170°C for 30 minutes.

[0294]

(7) Subsequently, via-hole openings 6 with a diameter of 80μm were formed in the interlayer resin insulation layers 2 via a CO_2 gas laser with a wavelength of 10.4μm through a 1.2 mm-thick mask having penetration holes under conditions: a beam diameter of 4.0 mm, a top hat mode, a pulse width of 8.0 μs, a diameter of the penetration holes of the mask of 1.0 mm, and one shot (see Fig. 14(a)).

[0295]

(8) The substrate in which the via-hole openings 6 were formed was immersed in a solution containing 60 g/l of permanganic acid at 80°C for 10 minutes to dissolve and remove the epoxy resin particles existing in the surfaces of the interlayer resin insulation layers 2, to thereby form the roughened surfaces (not shown) in the interlayer resin insulation layers 2 including the inner wall surfaces of the via-hole openings 6.

[0296]

(9) Subsequently, the substrate subjected to the above-described process was immersed in a neutralizer (made by Shipley Co.), and washed with water. Further, a palladium catalyst was provided to the surface of the substrate subjected to the surface roughening process (the roughening depth: 3 μm), so that catalyst core was adhered to the surfaces of the interlayer resin insulation layers 2 (including the inner wall surfaces of the via-hole openings 6) (not shown). Specifically, the substrate was immersed in a catalyst solution containing palladium chloride ($PdCl_2$) and stannous chloride ($SnCl_2$), and palladium metal was precipitated, to thereby provide the catalyst.

[0297]

(10) Subsequently, the substrate was immersed in an electroless copper plating aqueous solution to thereby form

electroless copper plating films 12 with a thickness of 0.6 to 3.0 μm on the surfaces of the interlayer resin insulation layers 2 (including the inner wall surfaces of the via-hole openings 6) (see Fig. 14(b)). The electroless copper plating aqueous solution which was used, and the electroless plating conditions were similar to those employed in the step (10) of the process of producing the IC chip implementation substrate.

[0298]

(11) Subsequently, a commercially available photosensitive dry film was laminated to the substrate on which the electroless copper plating films 12 were formed; a mask was put thereon; and exposure at a dose of 100 mJ/cm^2 and development with an aqueous 0.8% sodium carbonate solution were performed to thereby provide plating resists 3 with a thickness of 20 μm (see Fig. 14(c)).

[0299]

(12) Subsequently, the substrate was washed with water at 50°C to degrease, washed with water at 25°C, and further washed with sulfuric acid. Thereafter, the substrate was subjected to electroplating under the following conditions to thereby form electroplating copper films 13 with a thickness of 20μm on the plating-resist-3 non-formed part (see Fig. 14(d)). The electroplating solution which was used, and the electroplating conditions were similar to those employed in the step (12) of the process of producing

the IC chip implementation substrate.

[0300]

(13) After detaching and removing the plating resists 3 with 5% NaOH, the electroless plating films under the plating resists 3 were etched, dissolved and removed with a solution mixture of sulfuric acid and hydrogen peroxide, to thereby form conductor circuits 5 (including via-holes 7) each made of the electroless copper plating film 12 and the electroplating copper film 13 and having a thickness of 18 μm (see Fig. 15(a)).

[0301]

(14) Further, roughened surfaces (not shown) were formed in the surface of the conductor circuits 5, using an etchant similar to that used in the step (5). Subsequently, interlayer resin insulation layers 2 having via-hole openings 6 and having roughened surface (not shown) formed in the surface thereof were formed in a stacked manner by a process similar to that employed in the steps (6) to (8) (see Fig. 15(b)). Thereafter, optical-path penetration holes 8 passing through the substrate 1 and the interlayer resin insulation layers 2 were formed via a drill with a diameter of 300 μm, and a desmear process was performed to the wall surfaces of the optical-path penetration holes 8 (see Fig. 15(c)). It should be noted that the diameter of the drill used when the optical-path penetration holes are formed is preferably from 200 to 400 μm, and, with regard

to this example, a drill with a diameter of 300 μm was used.

[0302]

(15) Subsequently, by a method similar to that employed in the step (9), a catalyst was provided to the surfaces of the wall surfaces of the optical-path penetration holes 8 and the surfaces of the interlayer resin insulation layers 2. Then, the substrate was immersed in an electroless copper plating aqueous solution similar to the electroless plating solution used in the step (10), to thereby form thin film conductor layers (electroless copper plating films) 12 on the surfaces of the interlayer resin insulation layers 2 (including the inner wall surfaces of the via-hole openings 6), and the wall surfaces of the optical-path penetration holes 8.

[0303]

(16) Subsequently, by a method similar to that employed in the step (11), plating resists 18 were provided all over the interlayer resin insulation layers 2 (except the portions of the thin film conductor layer 12 formed on the wall surfaces of the optical-path penetration holes 8). The substrate was then immersed in an electroless gold plating solution containing potassium gold cyanide (7.6 x 10^{-3} mol/l), ammonium chloride (1.9 x 10^{-1} mol/l), sodium citrate (1.2 x 10^{-1} mol/l), and sodium hypophosphite (1.7 x 10^{-1} mol/l) for 7.5 minutes under the condition of 80°C to thereby form a metal layer (a gold plating layer) 16

on the wall surfaces of the optical-path penetration holes 8 (see Fig. 16(a)). Thereafter, the plating resists 18 was detached and removed with 5% NaOH.

[0304]

(17) Subsequently, by a method similar to that employed in the step (11), plating resists 3 were provided to the part including the end face portions of the optical-path penetration holes having the metal layer 16 formed therein. In addition, by a method similar to that employed in the step (12), electroplating copper films 3 with a thickness of 20μm were formed on the plating-resist-13 non-formed part (see Fig. 16(b)).

[0305]

(18) Subsequently, by a method similar to that employed in the step (13), detaching of the plating resists 3 and removing of the thin film conductor layer under the plating resists 3 were performed, to thereby form conductor circuits 5 (including via holes 7) (see Fig. 16(c)).

[0306]

(19) Subsequently, a resin composite containing epoxy resin was filled into the optical-path penetration holes 8 having the metal layer 16 formed therein, using a squeegee, and was then dried. Thereafter, the surface thereof was planarized by buffing. Further, a curing process was performed to thereby form an optical-path resin layer 20 (see Fig. 17(a)). In addition, by a method similar to that

employed in the step (2), an oxidizing-reducing process was performed to thereby turn the surfaces of the conductor circuits 5 into roughened surfaces (not shown).

[0307]

(20) Subsequently, optical waveguides 18 (18a, 18b) having optical-path changing mirrors 19 (19a, 19b) were formed at predetermined positions on the surfaces of the interlayer resin insulation layer 2 and the optical-path resin layer 20, by the following method. Specifically, film-shaped optical waveguides (made by STEAG microParts GmbH., width: 25 μm, thickness: 25 μm) made of PMMA and each having the 45° optical-path changing mirror 19 which had been formed beforehand at one end thereof using a diamond saw having a 90° V-shaped tip, were bonded so that the side face of the optical waveguide at the other end which is on the optical- changing mirror non-formed side, and the side face of the interlayer resin insulation layer were in plane. The bonding of the optical waveguides was performed by applying, at a thickness of 10 μm, an adhesive comprising thermosetting resin onto the bonding surface of the optical waveguide bonded to the interlayer resin insulation layer, performing pressure lamination, and then curing the adhesive at 60°C for an hour. Although, in this example, the curing was performed under the conditions at 60°C for an hour, step curing may be performed in some cases. This is because stress is less prone to occur in the optical

waveguide during bonding.

[0308]

(21) Subsequently, by a method similar to that employed in the step (20) of the process of producing the IC chip implementation substrate, a solder resist composite was prepared. The solder resist composite was applied, at a thickness of 30 μm, to each side of the substrate on which the interlayer resin insulation layers 2 and the conductor circuits 5 (including via-holes 7) had been formed, and then dried under conditions of 70°C for 20 minutes, and 70°C for 30 minutes, to thereby form solder resist composite layers 14' (see Fig. 17(b)).

[0309]

(22) A photomask with a thickness of 5 mm on which a pattern of the solder-bump forming openings (openings for connection with a package substrate) and the optical-path openings was drawn was placed closely to the solder resist layer on one side of the substrate, and the exposure to UV light at 1000 mJ/cm^2 was performed. Then, a development process was performed with the DMTG solution to thereby form openings. Further, a heat process was performed at 80°C for an hour, 100°C for an hour, 120°C for an hour, and 150°C for 3 hours to cure the solder resist composite layers, to thereby form solder resist layers 14 with a thickness of 20 μm having optical-path openings 11 and solder-bump forming openings 15 (see Fig. 18(a)).

[0310]

(23) Subsequently, a resin composite similar to that containing epoxy resin filled in the step (19) was filled into the optical-path openings formed in the step (22), using a squeegee, and was then dried. Thereafter, the surface thereof was planarized by buffing. Further, a curing process was performed to thereby form an optical-path resin layer 20. With regard to the optical-path resin layer formed in this step, and that formed in the step (19), the transmittance was 85%, and the refractive index was 1.60.

[0311]

(24) By a process similar to that employed in the step (24) of the process of producing the IC chip implementation substrate, nickel plating layers and gold plating layers were formed to thereby obtain solder pads.

[0312]

(25) Subsequently, solder paste was applied to the solder-bump forming openings 15 formed in the solder resist layers 14 by printing, and then, reflow was performed at 200°C to form solder bumps 17 in the solder-bump forming openings 15, to thereby obtain an multilayer printed wiring board (see Fig. 18(b)).

[0313]

C. Manufacture of Optical communication device with IC implemented thereon

First, an IC chip was implemented on the IC chip implementation substrate manufactured through the steps of the process A, and then sealed with resin, to thereby obtain a IC chip implementation substrate. Subsequently, this IC chip implementation substrate and the multilayered printed circuit board manufactured through the steps of B were placed so as to face each other in predetermined positions, and then reflow was performed at 200°C to connect the solder bumps of both of the substrate and the board to form solder connections, to thereby manufacture a optical communication device (see Fig. 4). In the optical communication device shown in Fig. 4, the light-signal transmitting optical path includes the resin composite, the cavities, and the surrounding metal layer. However, with regard to the optical communication device manufactured by the method of this example, it is constituted of the light-signal transmitting optical path includes the resin composite, and the surrounding metal layer.

[0314]

(Example 2)

Instead of the gold plating layer formed on the electroless copper plating film in the step (16) of the process A, and the step (16) of the process B of the example 1, a metal layer (a silver plating layer) was formed on the wall surfaces of the optical-path penetration holes

by immersing the substrates in an silver electroplating solution containing AgCN (5 g/l), KCN (60 g/l), and K_2CO_3 (15g/l) for 8 minutes under the conditions: a temperature of 25°C, and a current density of 1.0 A/dm^2. Thereafter, by a process similar to that employed in the example 1 except that no optical-path resin layer 42 was formed in the steps (19) and (23) of the process A of the example 1, and that no optical-path resin layer 20 was formed in the steps (19) and (23) of the process B thereof, an optical communication device was manufactured. With regard to an IC chip implementation substrate and a multilayer printed wiring board produced by the method of this example, the light-signal transmitting optical path includes a cavity, and the surrounding metal layer.

[0315]

(Example 3)

Instead of the gold plating layer formed on the electroless copper plating film in the step (16) of the process A, and the step (16) of the process B of the example 1, a metal layer (a nickel plating layer) was formed on the wall surfaces of the optical-path penetration holes by immersing the substrates in an electroless nickel plating solution having pH 4.5 and containing nickel chloride (2.3 x 10^{-1} mol/l), sodium hypophosphite (2.8 x 10^{-1} mol/l), and sodium citrate (1.6 x 10^{-1} mol/l) for 20 minutes. Thereafter, by a process similar to that employed

in the example 1 except that the step of filling a resin composite into the optical-path openings was not performed in the step (23) of the process A of the example 1, and that no resin composite was filled into the optical-path openings in the step (23) of the process B thereof, an optical communication device was manufactured. With regard to an IC chip implementation substrate and a multilayer printed wiring board produced by the method of this example, the light-signal transmitting optical path includes the resin composite, cavities, and the surrounding metal layer (see Fig. 4).

[0316]

(Example 4)

An optical communication device was manufactured by a process similar to that employed in the example 1 except that a sealing resin composite was filled into the space between the an IC chip implementation substrate and a multilayer printed wiring board which were connected to each other via solder connections, and thereafter, a curing process was performed to thereby form a sealing resin layer. As the sealing resin composite, a resin composite containing epoxy resin was used. With regard to the formed sealing resin layer, the transmittance was 85%, and the refractive index was 1.60.

[0317]

(Example 5)

An IC chip implementation substrate was produced by a process similar to that employed in the example 1 except that, instead of the gold plating layer formed on the electroless copper plating film in the step (16) of the process A of the example 1, a metal layer (a platinum plating layer) was formed on the wall surfaces of the optical-path penetration holes by immersing the substrate in a platinum electroplating solution containing $PtCl_4 \cdot 5H_2O$ (4 g.l), $NH_2HPO_4 \cdot 12H_2O$ (100 g.l), and $(NH_4)_2HPO_4$ (20 g.l) for 10 minutes under the conditions: a temperature of 60°C, and a current density of 1.0 A/dm^2. Thereafter, by a process similar to that employed in the example 1 except that the step of forming the light-signal transmitting optical path in the steps (14) to (19), (22), and (23) of the process B of the example 1, an optical communication device was manufactured.

[0318]

(Example 6)

An optical communication device was manufactured by a method similar to that employed in the example 5 except that no resin composite was filled into the optical-path openings in the step (23) of the process A of the example 1. With regard to an IC chip implementation substrate produced by the method of this example, a light-signal transmitting optical path includes a resin composite, cavities, and a surrounding metal layer (see Fig. 1).

[0319]

(Example 7)

An IC chip implementation substrate was produced by a process similar to that employed in the process A of the example 1, with the following exceptions: the step of forming the light-signal transmitting optical path was not performed in the steps (14) to (19), (22), and (23) of the process A of the example 1; in the step (22) of the process A of the example 1, a photomask on which a pattern of the optical-element implementing openings was drawn was placed closely to the solder resist composite layer on the side onto which the multilayer printed wiring board was to be connected, and an exposure and development process was performed to thereby form optical-element implementing openings; and, thereafter, solder paste was applied to the optical-element implementing openings by printing, and reflow was performed at 200°C to thereby implement the light receiving element and the light emitting element via solder. Thereafter, by performing the processes B and C of the example 1, an optical communication device was manufactured.

[0320]

(Example 8)

An optical communication device was manufactured by a method similar to that employed in the example 7 except that no resin composite was filled into the optical-path

openings in the steps (19) and (23) of the process B of the example 1. With regard to a multilayer printed wiring board produced by the method of this example, a light-signal transmitting optical path includes a cavity, and a surrounding metal layer.

[0321]

(Example 9)

An optical communication device was manufactured by a method similar to that employed in the example 1 except that, after the step (24) of the process A of the example 1 was performed, a microlens was disposed in the optical-path resin layer at an end thereof on the side onto which the multilayer printed wiring board was to be connected, by the following method. Specifically, at the end of the optical-path resin layer, epoxy resin was dripped via a dispenser, and then, a curing process was performed to thereby form the microlens. The transmittance of the microlens formed in this process was 92%, and the refractive index thereof was 1.62.

[0322]

(Comparative Example 1)

An optical communication device was manufactured by a method similar to that employed in the example 1, with the following exceptions: no metal layer was formed on the wall surfaces of the optical-path penetration holes in the step (16) of the process A, and the step (16) of the process

B of the example 1; electroplating copper films were formed on the wall surfaces of the optical-path penetration holes in the step (17) of the process A and the step (17) of the process B; and, thereafter, a blackening process using, as a blackening bath, an aqueous solution containing NaOH (10 g/l), $NaClO_2$ (40 g/l), and Na_3PO_4 (6 g/l), and a reducing process using, as a reducing bath, an aqueous solution containing NaOH (10 g/l) and $NaBH_4$ (6 g/l) were performed.

[0323]

Concerning the optical communication devices of the examples 1 to 9, and the comparative example 1 obtained in this way, simulation about the optical path of light signals exhibited when the light signals are transmitted from the surface of the optical waveguide facing the light receiving element, which surface is exposed from the multilayer printed wiring board, was conducted on the basis of the design parameters of each of the optical communication devices, such as the spectral reflectance of the glossy metal layer, the length of the light-signal transmitting optical path, the diameter of the cross section of the light-signal transmitting optical path, and the light emission angle of the light emitting element. As a result, it is apparent that, with regard to the optical communication devices of the examples 1 to 9, desired light signals can be received at the surface of the optical waveguide facing the light emitting element, which surface

is exposed from the multilayer printed wiring board, and that the optical communication devices manufactured by the methods of the examples 1 to 9 have satisfactory performance as an optical communication device. It should be noted that, with regard to the example 9, the radius of curvature of the microlens was taken into consideration as the design parameter.

[0324]

On the other hand, the result of conducting the simulation concerning the optical communication device of the comparative example 1 has shown the following: when a light signal transmitted in the light-signal transmitting optical path impinges on the wall surface of the light-signal transmitting optical path, diffuse reflection of light occurs, and therefore, the loss of the light signal occurs, accordingly a desired light signal cannot be received at the surface of the optical waveguide facing the light emitting element, which surface is exposed from the multilayer printed wiring board, in some cases; and the optical communication device of the comparative example 1 has insufficient performance as an optical communication device. Further, the simulation conducted by the above method concerning an optical communication device similar to that of the comparative example 1 except that optical-path penetration holes passing through a substrate and interlayer resin insulation layers were

formed, and that, after a desmear process was performed to the wall surfaces of the optical-path penetration holes, a resin composite was filled into the optical-path penetration holes, has shown a result similar to that concerning the optical communication device of the comparative example 1.

[0325]

Incidentally, when, concerning the optical communication device of the comparative example 1, conducted was simulation in which the length of the light-signal transmitting optical path was set at such a length that a light signal will not impinge on the wall surface of the light-signal transmitting optical path, a desired light signal could be received at the surface of the optical waveguide facing the light emitting element, which surface was exposed from the multilayer printed wiring board.

[0326]

By the method described below, measured was the waveguiding loss between the light emitting element implemented on the IC chip implementation substrate of the optical communication device of each of the examples 1 to 9, and the optical waveguide formed in the multilayer printed wiring board, which waveguide faces this light emitting element. The result has shown that the waveguiding loss is low, and that a light signal can be

transmitted satisfactorily. The measurement of the waveguiding loss was conducted through the following process: the multilayer printed wiring board was cut using an edge tool so that the section passed through the optical waveguide facing the light receiving element to thereby expose an end face of the optical waveguide; an optical fiber was attached to the exposed face; a power meter was attached to the light receiving element via an optical fiber; thereafter, a light signal with a measurement wavelength of 850 nm was transmitted from the exposed face; and the light signal transmitted to the light receiving element via the optical waveguide and the light-signal transmitting optical path was detected by the power meter.

[0327]

[Effects of the Invention]

As described above, in each of the optical communication devices of the first to third aspects of the present invention, in at least one of the IC chip implementation substrate and the multilayer printed wiring board, the light-signal transmitting optical path having the glossy metal layer formed on part of or all over the wall surface thereof is disposed, and the glossy metal layer can favorably reflect the light signal transmitted in the light-signal transmitting optical path, therefore the light signal is less prone to be attenuated or absorbed when impinging on the wall surface of the light-signal

transmitting optical path. Accordingly, with the optical communication devices of the first to third aspects of the present invention, since the loss of the light signal transmitted in the light-signal transmitting optical path is less prone to occur, the optical communication device is excellent in the light-signal transmission reliability, making it possible to realize reliable optical communication. In addition, with regard to the optical communication devices of the present invention, since the light-signal transmitting optical path has the features as described above, it is possible to favorably transmit light signals even if the design is such that the light signals will be reflected by the light-signal transmitting optical path.

[0328]

In addition, in each of the optical communication devices of the first to third aspects of the present invention, if a light receiving element and a light emitting element are implemented at predetermined positions on the IC chip implementation substrate, optical waveguides are formed at predetermined positions in the multilayer printed wiring board, and light-signal transmitting optical paths of the form described above are formed in at least one of the IC chip implementation substrate and the multilayer printed wiring board, the connection loss between the implemented optical components is low, and the optical

communication device is excellent in the connection reliability as an optical communication device.

[0329]

With regard to the methods of manufacturing an optical communication device of the fourth to sixth aspect of the present invention, since the step of forming the glossy metal layer on the wall surface of the light-signal transmitting optical path is included, it is possible to favorably manufacture such an optical communication device in that no loss of the light signal transmitted in the light-signal transmitting optical path occurs, and the optical communication device is therefore excellent in the light-signal transmission reliability, making it possible to realize reliable optical communication.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a sectional view schematically showing an embodiment of the optical communication device of the first aspect of the present invention.

[Fig. 2]

Fig. 2 is a sectional view schematically showing another embodiment of the optical communication device of the first aspect of the present invention.

[Fig. 3]

Fig. 3 is a sectional view schematically showing an embodiment of the optical communication device of the

second aspect of the present invention.

[Fig. 4]

Fig. 4 is a sectional view schematically showing an embodiment of the optical communication device of the third aspect of the present invention.

[Fig. 5]

Fig. 5 is a sectional view schematically showing another embodiment of the optical communication device of the third aspect of the present invention.

[Fig. 6]

Fig. 6 is a sectional view schematically showing still another embodiment of the optical communication device of the third aspect of the present invention.

[Fig. 7]

Fig. 7 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fourth and sixth aspect of the present invention.

[Fig. 8]

Fig. 8 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fourth and sixth aspect of the present invention.

[Fig. 9]

Fig. 9 is a sectional view schematically showing part of the methods of manufacturing an optical communication

device of the fourth and sixth aspect of the present invention.

[Fig. 10]

Fig. 10 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fourth and sixth aspect of the present invention.

[Fig. 11]

Fig. 11 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fourth and sixth aspect of the present invention.

[Fig. 12]

Fig. 12 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fourth and sixth aspect of the present invention.

[Fig. 13]

Fig. 13 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fifth and sixth aspect of the present invention.

[Fig. 14]

Fig. 14 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fifth and sixth aspect of the present

invention.

[Fig. 15]

Fig. 15 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fifth and sixth aspect of the present invention.

[Fig. 16]

Fig. 16 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fifth and sixth aspect of the present invention.

[Fig. 17]

Fig. 17 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fifth and sixth aspect of the present invention.

[Fig. 18]

Fig. 18 is a sectional view schematically showing part of the methods of manufacturing an optical communication device of the fifth and sixth aspect of the present invention.

[Description of Reference Numerals]

100, 200, 300, 400, 500, 600 multilayer printed wiring board

101, 202, 301, 401, 501, 601 substrate

102, 202, 302, 402, 502, 602 interlayer resin insulation layer

104, 204, 304, 404, 504, 604 conductor circuit

107, 207, 307, 407, 507, 607 via hole

208, 361, 461, 561, 661 light-signal transmitting optical path

208a, 361a, 461a, 561a, 661a optical-path resin layer

208b, 361b, 461b, 561b, 661b metal layer

109, 209, 309, 409, 509, 609 through hole

111, 211 optical-path opening

114, 214, 314, 414, 514, 614 solder resist layer

118, 218, 318, 418, 518, 618 optical waveguide

119, 219, 319, 419, 519, 619 optical- changing mirror

120, 220, 320, 420, 520, 620 IC chip implementation substrate

121, 221, 321, 421, 521, 621 substrate

122, 222, 322, 422, 522, 622 interlayer resin insulation layer

124, 224, 324, 424, 524, 624 conductor circuit

127, 227, 327, 427, 527, 627 via hole

129, 229, 329, 429, 529, 629 through hole

134, 234, 334, 434, 534, 634 solder resist layer

137, 237, 337, 437, 537, 637 solder bump

138, 238, 338, 438, 538, 638 light receiving element

139, 239, 339, 439, 539, 639 light emitting element

140, 240, 340, 440, 540, 640 IC chip

151, 251, 351, 451, 551, 651 light-signal transmitting optical path

151a, 251a, 351a, 451a, 551a, 651a optical-path resin layer

151b, 251b, 351b, 451b, 551b, 651b metal layer

150, 250, 350, 450, 550, 650 optical communication device

260 sealing resin layer

Continued from the front page

(51) Int.Cl.[7] Identification Code FI Theme Code

(Reference)

H05K 3/46		G02B 6/12	B	
		H01L 23/12	Q	
			N	

F term (Reference)

2H047 KA04 KB08 KB09 LA09 MA07
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TA05 TA11
5E338 AA03 BB02 BB13 BB25 BB75
BB80 CC01 CC10 CD11 EE22 05
5E346 AA15 AA42 BB16 BB20 CC60
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Fig.1

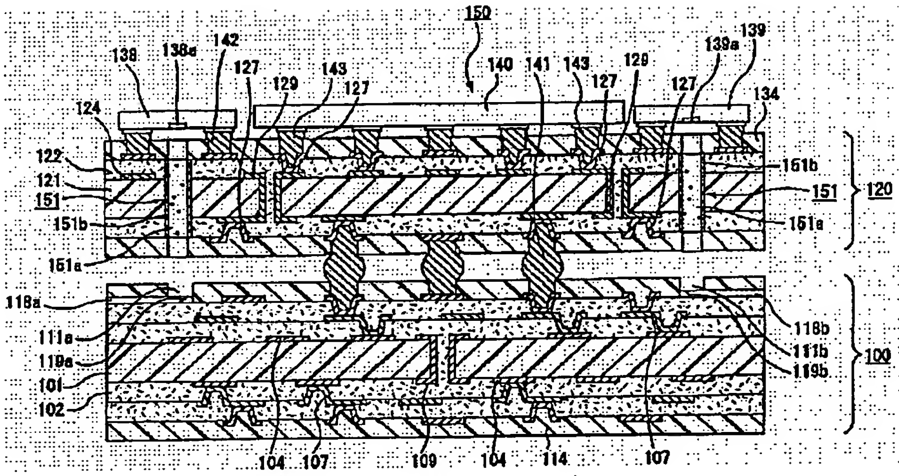
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Fig.2

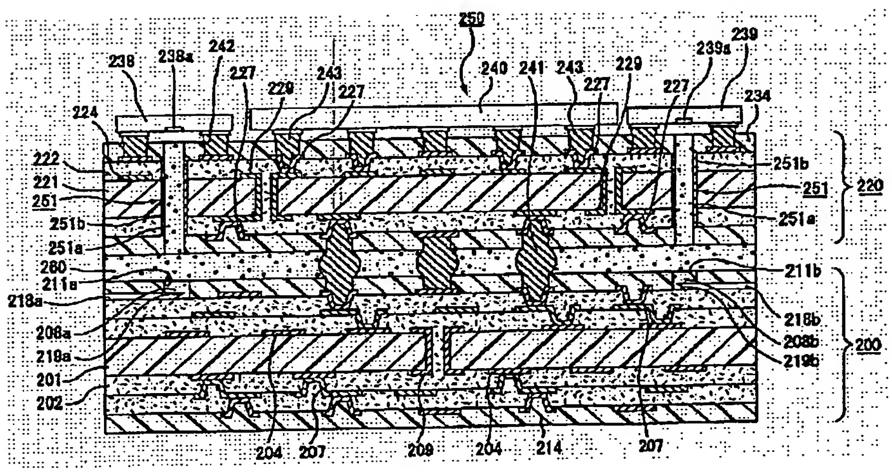
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Fig.3

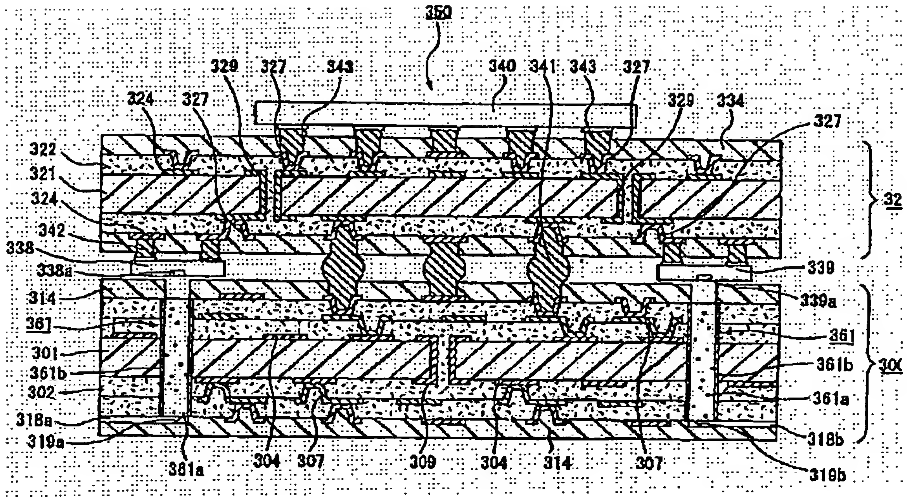
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Fig.4

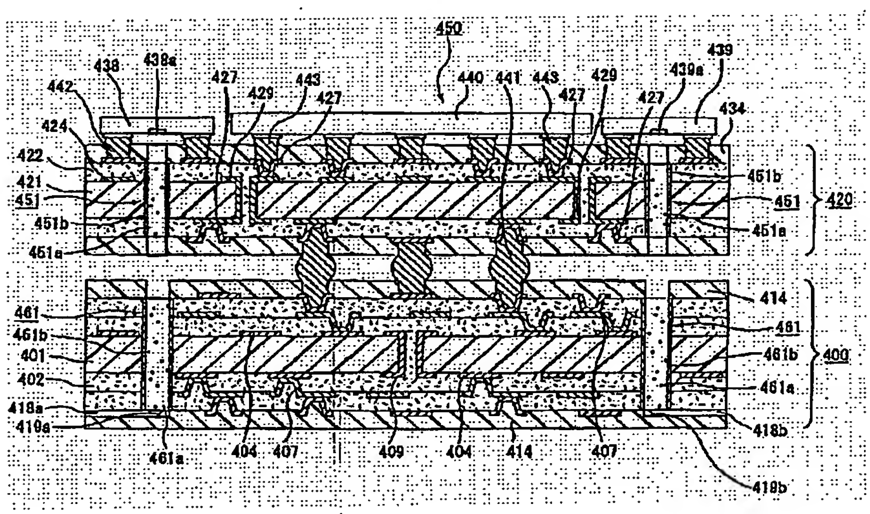
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Fig.5

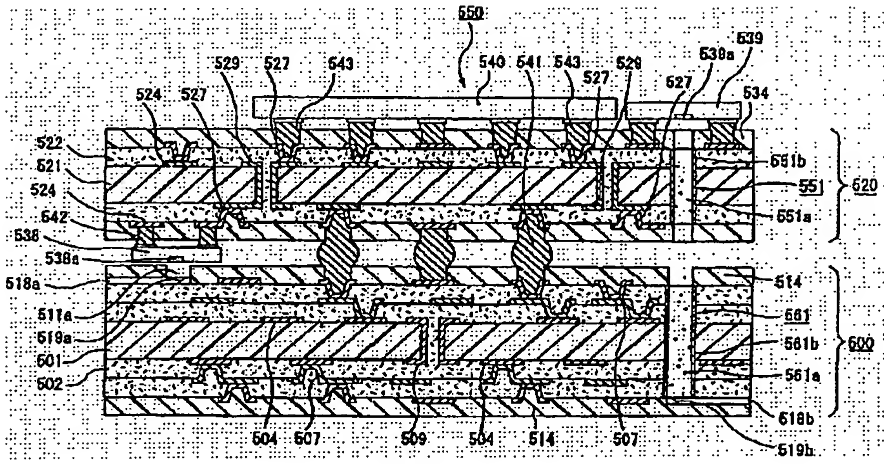

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Fig.6

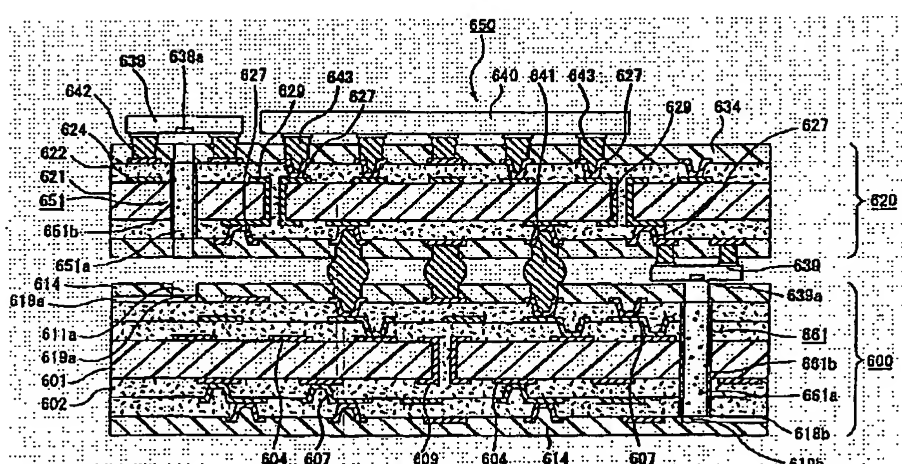

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Fig.7

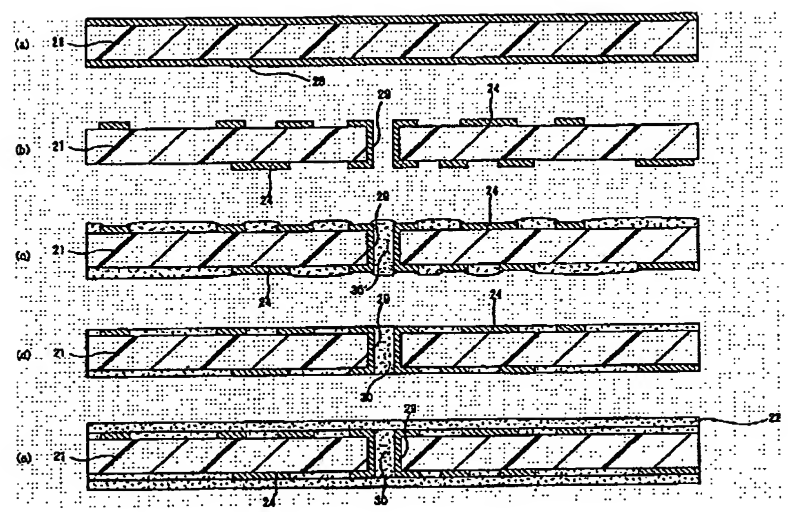


Fig.8

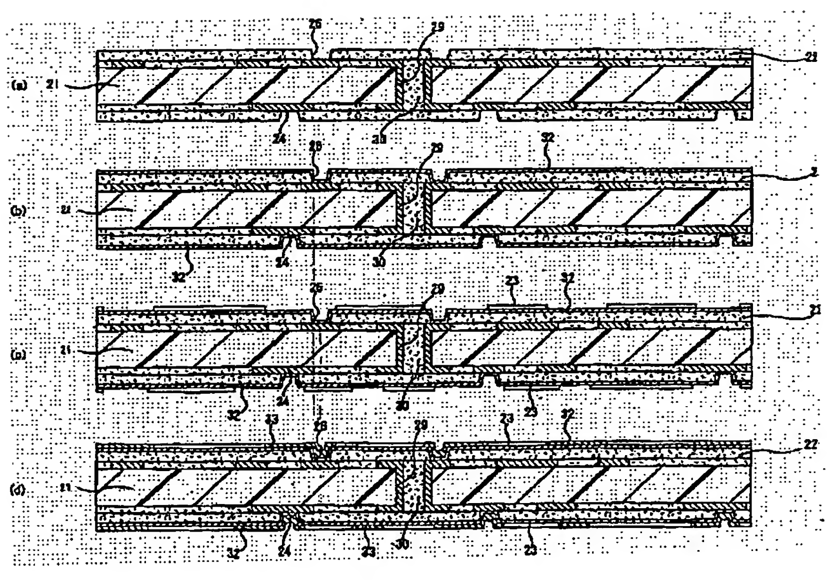


Fig.9

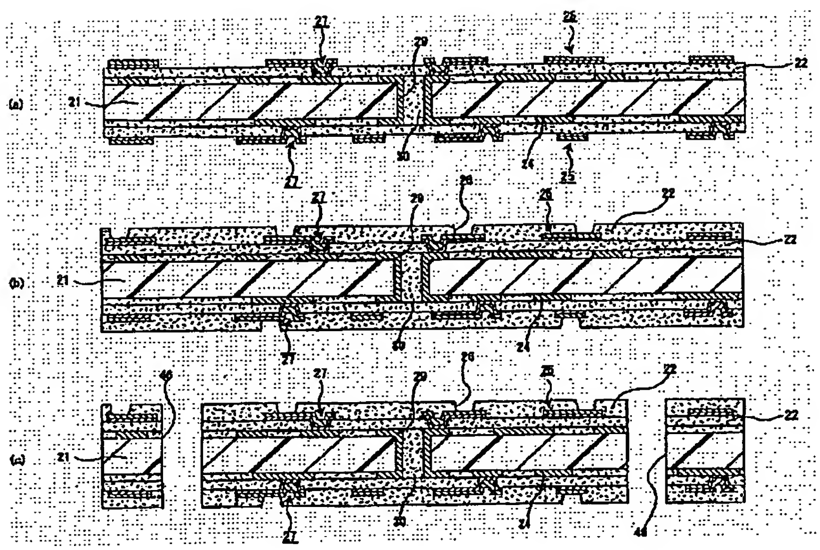


Fig.10

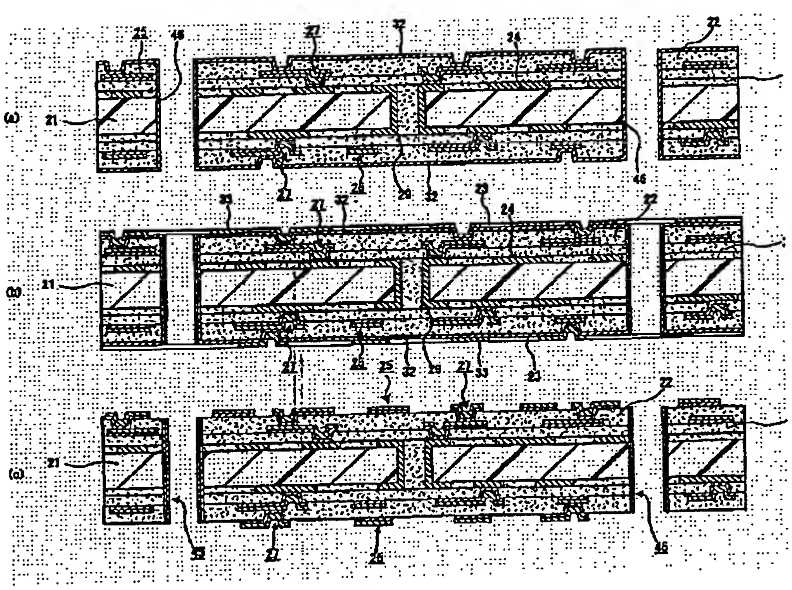


Fig.11

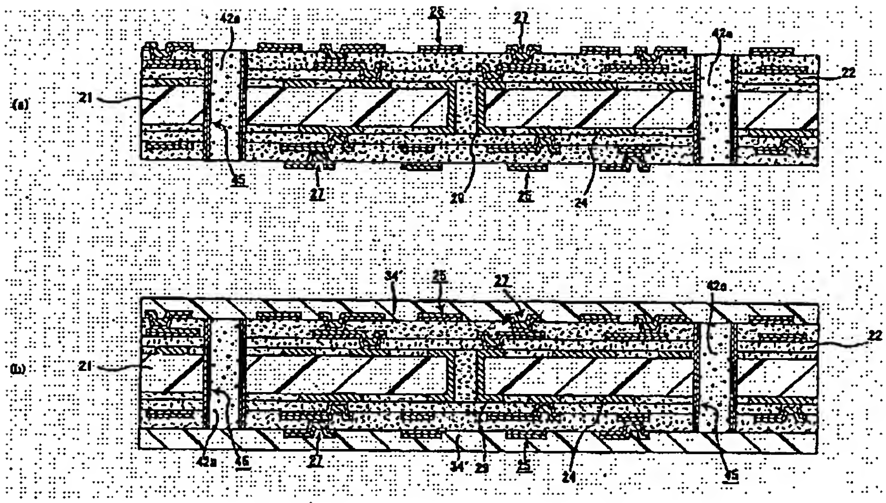


Fig.12

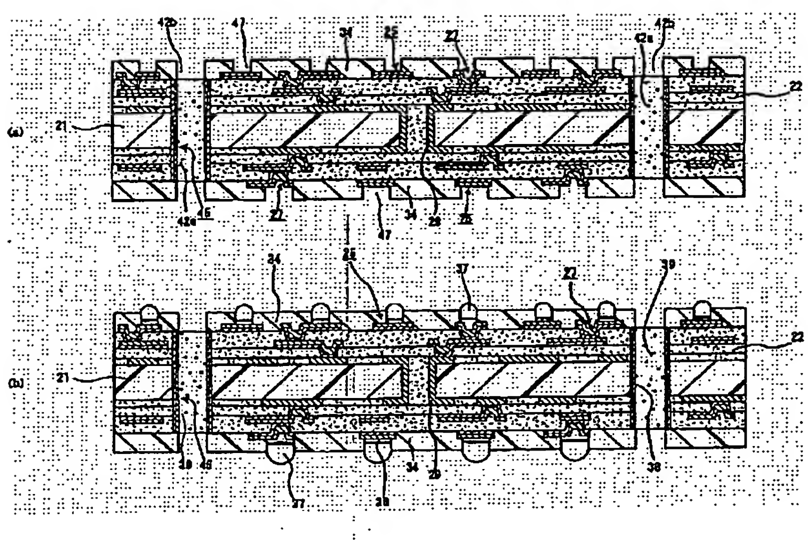
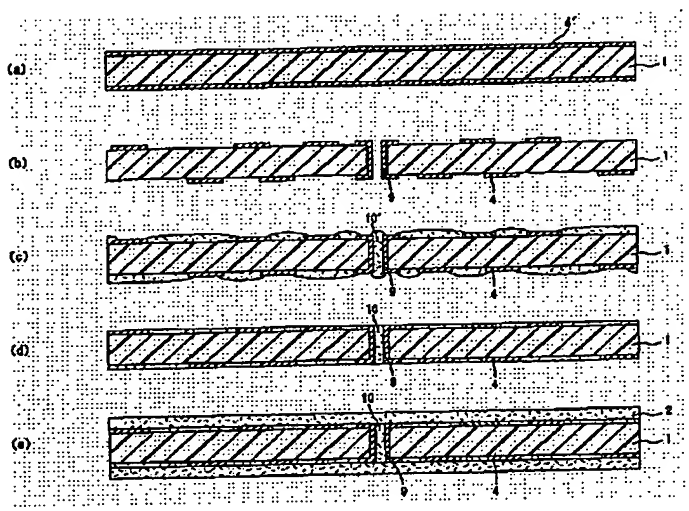


Fig.13



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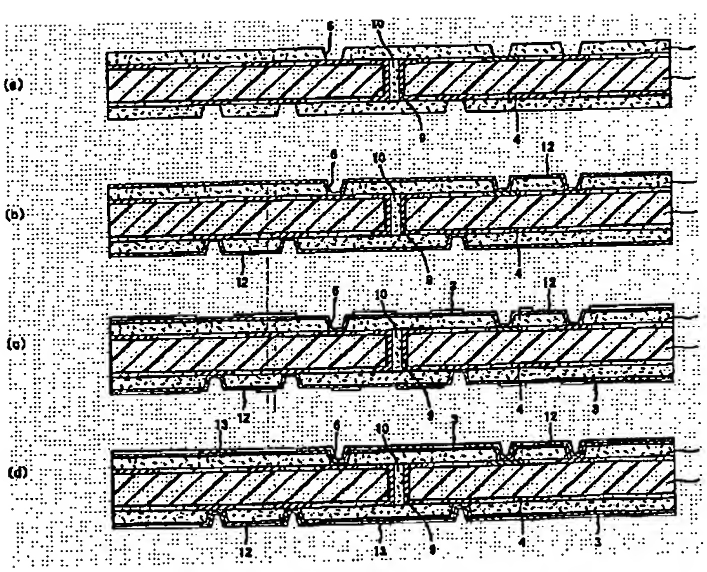

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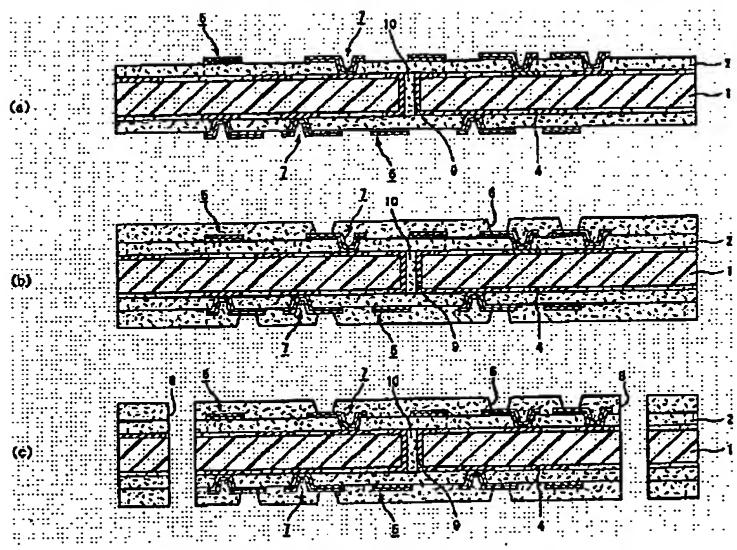

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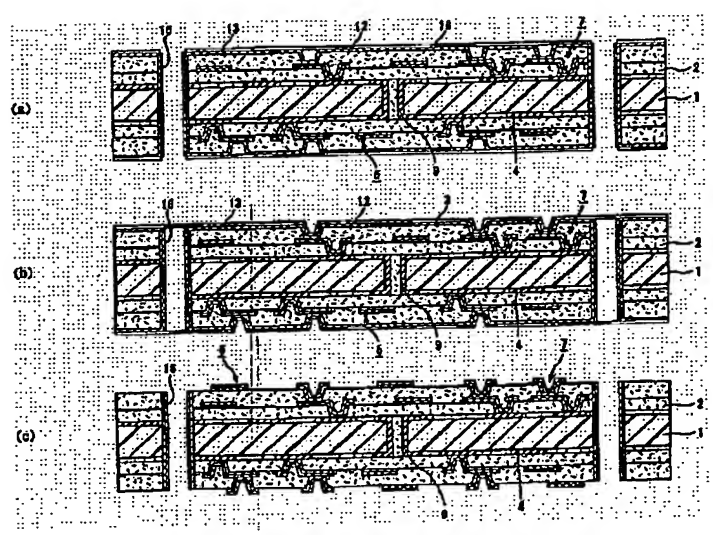

Fig.17

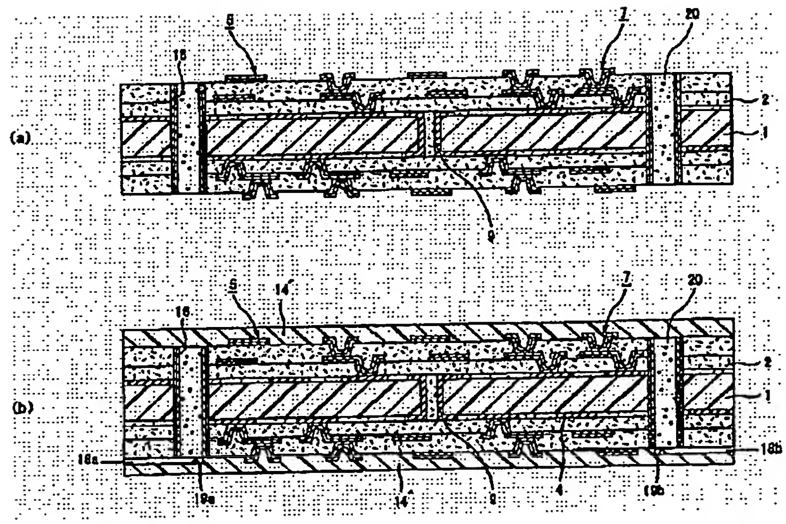

Fig.18